HEAVY METAL CONTAMINATION OF SPONTANEOUS VEGETATION AND SOIL AROUND THE COPPER SMELTER "LEGNICA".

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ABSTRACT

The area around the copper smelter "Legnica" in western Poland is influenced by pollutants from the smelter for about 35 years. Ecosystems within a distance of 1-2 km from the smelting complex are heavily degraded. Copper levels of the upper soil layers averaged more than 15000 ppm, lead levels more than 2000 ppm (d.m. weight). Besides heavy metals, sulphur dioxide is one of the most important pollutants affecting plant growth. Only few plant species are able to grow on those highly contaminated sites. Vegetation patches within zones of bare ground without any vegetation are mainly dominated by *Convolvulus arvensis*, *Agropyron repens*, *Calamagrostis epigeios* or *Sambucus nigra*. Leaf metal contents of *Artemisia vulgaris*, a plant which is a good bioindicator and also very frequent around the copper smelter, ranged: 665-2340 ppm Cu (d.m. weight), 215-2301 ppm Zn, 189-1031 ppm Pb and 0.75-12.4 ppm Cd according to the distance and exposition to the pollution source.

KEY WORDS: heavy metals, plant migration, copper smelter, sulfur dioxide, soil contamination.

INTRODUCTION

Copper smelters emit large quantities of pollutants, particularly heavy metals and SO₂ and often cause tremendous perturbations and changes of ecosystems in the surroundings. Much research work on this topic has been already done by scientists in the United Kingdom, Canada, USA, Scandinavia, Australia and other countries (see e.g. Gorham and Gordon 1960, Goodman and Roberts 1971, Wu and Bradshaw 1972, Hutchinson and Whitby 1974, Beavington 1975, Wu et al. 1975, Wood and Nash 1976, Goodman and Gemmell 1978, Freedman and Hutchinson 1980, Cox and Hutchinson 1981, Lobersli and Steinnes 1988) and also in Poland, especially in the Legnica copper smelter area (Drozd and Kowaliński 1977, Brej 1983, Fabiszewski 1983, Fabiszewski et al. 1983, Zabawski 1983).

Fig. 2. Overview map of the Legnica copper smelter area. Sketch after Zabawski 1983. I - VII : Sampling sites

Fig. 1. The Legnica copper smelter in Lower Silesia (Poland)

AREA OF STUDY AND METHODS

This study deals with spontaneously growing vegetation in the immediate vicinity of the Legnica copper smelter (shown i in Fig. 1) and heavy metals contamination of soil and of some characteristic plants which were analyzed along a transect from NW to SE of the smelter, according to the prevailing wind directions (Fig. 2).

TABLE 1. Heavy metal (Cu, Pb, Zn, Sd) concentrations and pH soil samples from the Legnica copper smelter area.

Site	Depth (cm)	Concentration in ppm d. m.				pH
		Cu	Pb	Zn	Cd	
I	0-10	2352	228	116	0.89	4.4
	10-20	2353	944	68	0.83	4.9
	20-50	88	19	66	0.31	5.6
	50-80	61	20	39	0.20	5.8
II	0-10	7491	2162	289	3.51	6.6
	10-20	2985	816	178	1.46	6.9
	20-50	138	32	41	0.13	6.7
	50-80	52	15	26	0.05	6.5
III	0-10	15443	1992	554	2.17	6.4
	10-20	3491	4226	196	0.90	7.6
	20-50	419	101	77	0.17	7.2
IV	0-10	2230	929	257	0.72	4.9
	10-20	484	187	262	0.52	5.8
	20-50	48	39	30	0.08	4.9
	50-80	9	42	16	0.05	6.6
V	0-10	575	304	142	0.39	4.5
	10-20	743	333	90	0.36	4.2
	20-50	62	56	83	0.39	4.4
	50-80	30	49	87	0.15	5.4
VI	0-10	372	146	113	0.43	6.0
	10-20	849	330	100	0.49	6.0
	20-50	136	59	81	0.33	4.6
	50-80	70	26	79	0.09	4.8
VII	0-10	48	38	49	0.28	7.5
	10-20	37	28	47	0.27	7.6
	20-50	36	21	42	0.18	7.9
	50-80	35	12	24	0.16	7.9

Sites upwind - I: 800 m NW; II: 500 m NW; III: 300 m NW
 Sites downwind - IV: 400 m SE; V: 900 m SE; VI: 1400 m SE; VII: 7 km SE (Koskowice). Sampling time: 2-10 October 1987.
 Extraction of air dried soil with conc. nitric acid.
 Heavy metal analysis: Cu and Zn: AAS with oxygen-acetylen flame, PB and Cu: AAS with graphit furnace, pH measured in 0.01 M CaCl₂

The copper smelter "Legnica" is located near the town Legnica in Lower Silesia in West Poland in the foreland of the Sudeten mountains. The former natural vegetation consisted mainly of oak-hornbeam forest (*Quercus-Carpinetum*) on nutrient rich soil and Scots pine-oak forest (*Pino-Quercetum*) on soil with a lower nutrient content. When the copper smelter was built up in the middle of the 50s of this century, the area around the smelter was chiefly agriculturally used and only few remnants of the former natural vegetation were left.

The soil in the vicinity of the smelter has been mainly sandy clay (soil type : Luvisol - Parabraunerde). During the last 35 years of operating the smelter, the area around the smelter within a radius of 1 to 2 km was heavily perturbed by levelling, deposition and by soil erosion and highly influenced by aerial pollution. The main components of emission are dust and fly ash rich in heavy metals, especially copper and lead, and SO₂. Mean concentration of sulphur dioxide is estimated at 0.4 mg/m³ (Fabiszewski et al. 1983) in the immediate vicinity of the pollution sources.

RESULTS AND DISCUSSION

During the time of operating the smelter, remnants of the former natural vegetation died back, agriculture has been given up around the smelter, and some revegetation trials with trees and shrubs were more or less successful. Except plantation fragments of recultivation experiments, at present, the ground around the copper smelter is either bare of any vegetation or covered by a patchy ruderal vegetation within a radius of 1 to 2 km. Table 1 shows the distribution of heavy metals at 4 soil depths along a transect 800 m NW to 1400 m SE of the copper smelter. Three sites are in the northwest and upwind of the copper smelter, 3 sites are in the southeast and downwind of the smelter. A further sampling site is about 7 km east of the copper smelter (near Koskowice).

The soil around the smelter is heavily contaminated by copper and lead up to a depth of 20 cm. On the most contaminated sites copper and lead levels are also significantly high in the subsoil. Maximum copper content in the surface soil is higher than 15000 ppm. Maximum lead concentration is more than 4000 ppm, maximum zinc content is more than 500 ppm, whereas maximum cadmium levels do not exceed 3.5 ppm (Tab. 1). Low pH values at some sites around the smelter indicate that acidification has occurred, apparently due to the high sulphur dioxide emissions from the smokestacks (Tab. 1). High acidity, however, leads to increased availability of heavy metals for plant uptake and enhanced washout of metals from the soil (Drozd and Kowaliński 1977).

According to the distance from the pollution source heavy metal concentrations of the upper soil layer are decreasing with increasing distance (Tab. 1). However, it is obvious that heavy metals contents of the surface soil are higher upwind than downwind the smelter. The reason for this surprising fact may be either that surface soil was eroded by wind and water (which is favoured by the slope of the area around the smelter) or soil was changed by man some years ago (Fabiszewski et al. 1983). It is likely that both occurred. A third point may be, that easterly winds with a lower wind speed favour deposition nearby the smelter in the westerly direction.

However, leaf contents of mugwort (*Artemisia vulgaris*), a plant which is a good indicator for heavy metal pollution (Rebele 1989), show that aerial heavy metal pollution is

TABLE 2. Heavy metal concentration of mugwort leaves (*Artemisia vulgaris*) in the vicinity of the Legnica copper smelter

Site	mean concentration (n=3) in ppm d.m. (s.d.)			
	Cu	Pb	Cd	Zn
I	739 (66)	259 (38)	1.67 (0.39)	301 (26)
II	988 (400)	263 (103)	1.37 (0.53)	261 (60)
III	1845 (504)	443 (98)	1.60 (0.51)	249 (60)
IV	2093 (220)	913 (59)	7.45 (4.34)	1962 (583)
V	1259 (158)	531 (110)	7.11 (3.30)	1702 (218)
VI	1537 (457)	725 (267)	5.40 (3.86)	1183 (496)
VII	103 (20)	28 (5)	0.28 (0.14)	81 (19)

Sites upwind = I: 800 m NW; II: 500 m NW; III: 300 m NW
 Sites downwind - IV: 400 m SE; V: 900 m SE; VI: 1400 m SE; VII: 7 km SE (Koskowice) Sampling time: 2-10 October 1987.
 Extraction of plant material with conc. nitric acid (leaves unwashed; dried at 105 °C). Heavy metal analysis: Cu and Zn: AAS with oxygen-acetylen flame, Pb and Cd: AAS with graphite furnace, Ph measured in 0.01 M CaCl₂.

TABLE 3. Range of heavy metal concentration in leaves of *Artemisia vulgaris* from industrial areas and background levels in Central Europe.

Site	ppm d.m.			
	Cd	Pb	Cu	Zn
Legnica (I-VI) copper smelter	0.75-12.40	189-1031	665-2340	215-2301
Koskowice (VII) rural area	0.28-0.53	25-34	84-124	64-101
Duisburg (Deutschland) copper refinery	1.87-2.75	225-285	47-48	623-840
Berlin copper smelter waste	0.60-1.06	12-26	74-161	126-213
Berlin industrial areas	0.20-3.48	3-55	11-232	38-303
Berlin Grünwald forest	0.47-1.81	2-4	7-13	110-130

TABLE 4. Number of species and life form spectra of vascular plants growing on industrial sites

	Legnica 87	Legnica 89*	51 Industrial areas Berlin**
Total number of species	41	102	596
Area	675 m ²	c. 2 km ²	3.05 km ²
Data of survey	2-10 Oct. 87	18 June '89	1982-1987
Life form	%	%	%
Phanerophytes (trees)	2.4	5.9	8.2
Phanerophytes (shrubs)	4.9	5.9	9.7
Chamaephytes (woody)	2.4	1.0	0.8
Chamaephytes (herbaceous)	-	2.0	3.5
Hemicryptophytes	53.7	46.1	37.1
Geophytes	19.5	14.7	8.4
Therophytes	17.1	24.5	29.9
Hydrophytes	-	-	1.5

* Floristic survey by Rebele (unpublished data)

** Floristic survey (Rebele 1988)

higher downwind the pollution source (Tab. 2). Maximum copper and zinc levels exceeded 2300 ppm, maximum lead concentration was more than 1000 ppm, maximum cadmium content was 12.4 ppm (Tab. 3). If we compare these data with concentration levels from other polluted and less polluted sites (Tab. 3), we must draw the conclusion that the area around the copper smelter "Legnica" is one of the heaviest polluted areas in Central Europe.

Which plants can tolerate such site conditions? To answer this question vegetation was studied along the transect at the sites near the smelter, where soil and plant samples were collected. If possible, at each site, 5 (I : 3; IV : 4) vegetation relevés were made, where all vascular plant species and their cover percentage were ascertained.

The total number of species on these 6 sites is very low. Only 41 vascular plant species were recorded. However, it is necessary to mention that the total number of species around the smelter is about 3 times higher. But this is also very low, if we compare these results with other studies in industrial areas with lower pollution loads (Tab. 4). If we look at the distribution of plant life forms, we can see that 54% of the 41 species are hemicryptophytes and about 20% are rhizomatous geophytes. The share of therophytes is relatively low and there are also only few phanerophytes and chamaephytes.

If we only consider the dominant or more frequent species (Tab. 5), we can see that the dominant and more frequent species are chiefly rhizome - geophytes (*Convolvulus arvensis*, *Calamagrostis epigeios*, *Tussilago farfara*, *Agropyron repens*, *Equisetum arvense*, *Cirsium arvense*). These species are able to grow even on the most contaminated sites. For example, it is known for *Calamagrostis epigeios*, that heavy metals can be accumulated in the roots (Rebele 1986).

TABLE 5. Dominant and most frequent species growing on heavily polluted sites in the vicinity of the copper smelter Legnica

Species	Mean cover %*	Frequent % **
Rhizome-geophytes		
<i>Convolvulus arvensis</i>	8.7	77.8
<i>Calamagrostis epigeios</i>	4.8	51.9
<i>Tussilago farfara</i>	4.6	29.6
<i>Agropyron repens</i>	3.3	48.1
<i>Equisetum arvense</i>	2.6	33.3
<i>Cirsium arvense</i>	0.4	48.1
Hemicryptophytes		
<i>Artemisia vulgaris</i>	4.4	51.9
<i>Humulus lupulus</i>	2.2	14.8
<i>Agrostis tenuis</i>	1.3	29.6
Phanerophytes		
<i>Sambucus nigra</i>	10.8	37.0

Species with * mean cover values > 1% or ** frequency > 40%.
6 sites; 5 x (5m x 5m) survey areas

But it is also necessary to mention that populations of bind-weed (*Convolvulus arvensis*) which are growing on the heaviest polluted sites, show reduced growth, delayed flowering and fruiting as compared with populations of lower contaminated sites (Fabiszewski 1983).

The most frequent hemicryptophyte is *Artemisia vulgaris* but *Artemisia* is growing rather sparsely on the most polluted sites and shows also necrosis. The only phanerophyte, which is rather frequent, is *Sambucus nigra*. *Sambucus nigra*, however, shows also leaf chlorosis and necrosis in most cases.

If we compare species composition and cover of surveys from the different sites downwind the smelter, we can see that next to the smelter there are only 8 species present. Except site I the total number of species increases with increasing distance from the smelter (Tab. 6). It is obvious that other typical ruderal plants which are less tolerant than rhizomatous geophytes like *Convolvulus arvensis* or *Calamagrostis epigeios*, play a greater role when pollution is less severe, for example *Artemisia vulgaris* or *Humulus lupulus*.

Characterizing the vegetation of heavily polluted sites near the copper smelter there are the following points to be mentioned:

- the total number of species and species density is very low - there is only patchy vegetation, chiefly built up by rhizomatous geophytes
- the number of therophytes is low
- there are almost no spontaneously growing trees. Only one shrub species is present more frequently.

Species which are able to grow on those highly polluted sites must be both tolerant to high concentration of heavy metals and sulphur dioxide. There is no typical heavy metal vegetation in terms of plant sociology (associations belonging to *Violetea calaminariae*). We did not find character species like *Minuartia verna* or heavy metal ecotypes of *Silene vulgaris*, *Cardaminopsis halleri*, and so on. The only exception

TABLE 6. Vegetation influenced by aerial pollution in the vicinity of the copper smelter Legnica - mean cover values (%)

Site *	I	II	III	IV	V	VI
	800 m NW	500 m NW	300 m NW	400 m SE	900 m SE	1400 m SE
Number of species	10	23	16	8	18	21
Rh - g						
<i>Convolvulus arvensis</i>	20.0	2.1	3.1	14.0	11.2	2.0
<i>Equisetum arvense</i>	11.2	4.4	0.2		0.02	
<i>Tussilago farfara</i>	2.0	13.0	0.01			12.4
<i>Carex hirta</i>	2.0		0.2		2.0	
<i>Agropyron repens</i>	0.4		7.0	10.0	1.4	1.2
<i>Scirpus sylvaticus</i>	0.1					
<i>Cirsium arvense</i>	0.02	0.6	1.1	0.4	0.2	0.02
<i>Calamagrostis epigeios</i>		11.8	10.0	1.0	1.6	4.2
H						
<i>Poa trivialis</i>	1.0		2.0			
<i>Agrostis tenuis</i>		4.4			2.4	1.2
<i>Artemisia vulgaris</i>		2.0	0.03	0.02	23.4	1.0
<i>Poa pratensis</i>		1.0	0.1			
<i>Daucus carota</i>		0.4				
<i>Achillea millefolium</i>		0.2				
<i>Taraxacum officinale</i>		0.06				
<i>Cichorium intybus</i>		0.04				
<i>Rumex obtusifolius</i>		0.02	0.04		4.6	1.0
<i>Medicago sativa</i>		0.02				
<i>Trifolium hybridum</i>		0.02				
<i>Echium vulgare</i>		0.02				
<i>Tanacetum vulgare</i>		0.02				
<i>Humulus lupulus</i>			1.0			12.4
<i>Saponaria officinalis</i>			0.5			
<i>Lolium perenne</i>			0.2	4.0		
<i>Dactylis glomerata</i>				3.2		
<i>Silene alba</i>					0.06	
<i>Hypericum perforatum</i>					0.02	0.1
<i>Urtica dioica</i>					0.02	0.02
<i>Arctium lappa</i>						1.0
<i>Vicia cracca</i>						0.02
Th						
<i>Polygonum aviculare</i>	0.1	3.2	0.4		0.02	0.4
<i>Anthemis arvensis</i>		3.0				0.06
<i>Medicago lupulina</i>		0.4			0.4	0.02
<i>Papaver rhoeas</i>		0.04				
<i>Anagallis arvensis</i>		0.02				
<i>Polygonum persicaria</i>					0.2	
<i>Stellaria media</i>						0.04
Ph, Ch						
<i>Sumbucus nigra</i>	10.0	11.0	10.0	10.0	12.0	12.0
<i>Rubus caesius</i>					0.04	0.4
<i>Rubus idaeus</i>					0.02	0.4
<i>Quercus spec.</i>						2.0

* 6 sites; 5 x (5m x 5m) survey area; data of survey: 2-10 October 1987
Rh - g: Rhizome-geophytes; H: Hemicryptophytes; Th, Therophytes;
Ph, Ch: Phanerophytes and Chamaephytes

is probably *Agrostis tenuis*, which is easily introduced by direct seeding.

Summarizing the above findings we characterize the actual spontaneously growing vegetation around the copper smelter as a degraded ruderal vegetation.

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SKAŻENIE ROLINNOŚCI NATURALNEJ I GLEBY W SĄSIEDZTWIE HUTY MIEDZI "LEGNICA"

STRESZCZENIE

Od ponad 30 lat obszar wokół huty miedzi "Legnica" jest silnie skażony metalami ciężkimi i siarką. Największą degradację wykazują ekosystemy występujące w odległości 1-2 km od zakładu hutniczego. Poziom miedzi w wierzchniej warstwie gleby w badanym terenie przekracza 15000 ppm, natomiast poziom ołowiu wynosi aż 2000 ppm. Poza metalami ciężkimi, destrukcyjny wpływ na wzrost i rozwój roślin w pobliżu huty wywiera emitowany w znacznych ilościach dwutlenek siarki. W tak ekstremalnych warunkach występuje zaledwie kilka gatunków roślin, które tworzą niewielkie płyty w obrębie strefy pozbawionej zwartej pokrywy roślinnej. Najczęściej spotykane, rosnące płatami gatunki pionierskie to: *Convolvulus arvensis*, *Agropyron repens*, *Calamagrostis epigeios* i *Sambucus nigra*. W przeprowadzonych badaniach zwrócono m.in. uwagę na dość pospolity gatunek, o dobrych właściwościach biowskaźnikowych - *Artemisia vulgaris*. Oznaczone zawartości niektórych metali w liściach tej rośliny, zebranej w sąsiedztwie huty, w zależności od odległości i ekspozycji, wynosiły: 665-2340 ppm Cu, 215-2301 Zn, 189-1031 Pb i 0.75-12.4 ppm Cd.

SŁOWA KLUCZOWE: metale ciężkie, migracja roślin, huta miedzi, dwutlenek siarki, skażenie gleby