Moehringia trinervia (L.) Clairv. — a bioindicator of heavy metal pollution of the environment

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Abstract

The concentrations of 5 heavy metals, Cd, Pb, Ni, Zn and Cu, were determined in *Moehringia trinervia* (L.) Clairv. collected from several sites in the Niepołomice Forest. This area is polluted by the numerous industrial plants of Kraków, mainly by the steel mill situated near the eastern city limits. The composite index obtained from the contents of the assayed elements was the basis for delineating 4 pollution zones of the forest: the western zone, which has the highest heavy metal pollution (closest to the steel mill), with a composite pollution index from 0.26 to 0.43; two moderate zones with indexes from 0.02 to 0.15 and from -0.02 to -0.12 and the least polluted zone in the eastern area of the forest with an index of -0.18 to -0.29. It was found that *Moehringia* is an exceptionally good cadmium accumulator. The concentration of this element in the above-ground parts of this plant averaged about $9 \mu\text{g g}^{-1}$.

Key words: *Moehringia trinervia*, heavy metals, pollution zones, cadmium

INTRODUCTION

Kraków has a population of approximately 800 thousand and numerous factories and electric power and heating plants. Its main source of pollution is the steel mill situated on the eastern city limits. The annual SO_2 emission over the Kraków metropolitan area is about 150,000 tons, dust emission is also approximately 150,000 tons. This dust contains high amounts of heavy metals (Garścia et al. 1984).

The Niepołomice Forest is a large (c. 12,000 ha) complex of evergreen and deciduous forests, situated 10–35 km east of the steel mill and the city of Kraków. Western winds prevail over this area and blow the emissions from Kraków over to the forest. In 1984, approximately 80t of dust per km² fell on the Niepołomice Forest. This dust contained 3300 kg Fe, 192 kg Zn, 21 kg Ni, 30 kg Pb, 8 kg Cu (Maneck i et al. 1988).

The Niepołomice Forest has been the object of ecological studies for many years (Grodzińska et al. 1984). The state of the Niepołomice Forest has been described using numerous bioindicators with several heavy metal and sulfur pollution zones being identified in this forest (Kiszk a 1977, Makomaska 1978, Grabowski 1981).

Mosses and lichens are used most often in the assessment of heavy metal pollution (Tyler 1972, Rühling and Tyler 1973, 1984, Grodzińska 1978, Grodzińska et al. 1987, 1990, Rühling et al. 1987). Higher plants are used less frequently as bioindicators (Molski et al. 1981, Chmielewski et al. 1985, Steinnes 1987).

Moehringia trinervia is a common species in the Niepołomice Forest complex, both in the deciduous and evergreen areas. Earlier studies have shown *Moehringia trinervia* to be an efficient accumulator of heavy metals, especially cadmium (Grodzińska, unpublished). The cadmium concentration in various vascular plants of the Niepołomice Forest floor, that is, those growing under the same conditions as *Moehringia*, equals about 1–2 µg g⁻¹ (Grodzińska and Berbeka 1980).

The objective of this study was to determine the concentrations of heavy metals in *Moehringia trinervia* and distinguish on this basis zones of degradation of the Niepołomice Forest complex environment caused by emissions from the steel mill and those from the Kraków metropolitan area.

MATERIAL AND METHODS

In June, 1984, 28 samples of *Moehringia trinervia* were collected from the Niepołomice Forest: 22 were from the southern, evergreen part of the forest, 6 from the northern (deciduous) part (Fig. 1). Gorce (western Carpathians) was chosen as the control site. The material from both localities, Niepołomice Forest and Gorce, was collected during blooming and seed setting.

Unwashed plants were first dried in air then at 105°C until they reached a constant weight. Only above-ground parts were used in the study. The crumbled material was mineralized in a mixture of NO₃ and HClO₄ (at a 4:1 ratio) and the heavy metal (Cd, Pb, Ni, Zn and Cu) content was determined spectrophotometrically using a Varian-Techtron model 1000 spectrophotometer.

Fig. 1. Localization of stands (1) and cadmium content of *Moehringia trinervia* in the Niepołomice Forest

The heavy metal index (S_j) was calculated according to a procedure suggested by Grodzńska (1978) from the formula:

$$S_j = \frac{\sum_{i=1}^{l=j} x_{ij} - \bar{x}_i}{\bar{x}_i},$$

where x_{ij} is the content of i -heavy metal in j -locations; $\bar{x}_i$ — the mean content of i -heavy metal in all locations; in this particular case, i equals 5 (Cd, Pb, Ni, Zn, Cu).

RESULTS

The heavy metal contents in *Moehringia trinervia* collected from the Niepołomice Forest and from the control sites in Gorce are presented in Table 1.

The heavy metal concentrations in *Moehringia trinervia* were high and distinctly greater in the western part of the forest than in the eastern part. Cadmium was accumulated at a level near 8–9 $\mu\text{g g}^{-1}$. The differences in the Cd

Table 1

Heavy metal concentrations ($\mu\text{g g}^{-1}$ d. wt) in *Moehringia trienrvia* collected in the Niepołomice Forest (zones: I-IV) and Gorce Mountains (1 — Przysłop, 2 — Ochotnica valley, 3 — Cebulówka)

Zone		Loca- lity	Cd	Pb	Ni	Zn	Cu	Index value
NIEPOŁOMICE FOREST	I	1	9.95	15.1	9.5	397.6	10.9	0.34
		2	6.71	18.7	10.3	337.1	9.3	0.28
		6	13.14	11.4	7.9	405.7	10.3	0.26
		7	7.14	10.6	10.3	368.6	23.7	0.43
		$\bar{x}$ SD	9.24 2.973	14.0 3.72	9.5 1.13	377.3 31.15	13.6 6.80	
	II	3	10.71	9.0	9.5	349.5	9.5	0.12
		5	6.85	7.3	7.9	328.1	13.5	0.03
		8	15.29	3.4	9.5	392.9	9.8	0.09
		9	9.62	7.9	8.9	375.5	9.5	0.07
		13	12.57	6.1	7.9	351.4	8.6	0.02
		25	11.67	6.1	11.7	457.1	7.3	0.12
		26	13.33	5.4	14.3	391.4	7.1	0.15
		27	11.44	4.9	12.4	366.9	7.6	0.05
		$\bar{x}$ SD	11.44 2.525	6.3 1.78	10.3 2.30	376.6 39.25	9.1 2.07	
	III	4	6.14	7.3	9.5	347.1	9.3	-0.03
		10	8.29	7.5	7.1	285.2	8.0	-0.10
		11	8.29	4.9	8.7	324.3	8.6	-0.10
		12	16.14	4.5	7.1	290.5	7.7	-0.02
		14	9.33	5.4	7.1	329.5	8.8	-0.09
		17	10.52	6.7	6.4	280.0	8.6	-0.08
		18	9.57	5.5	6.4	350.0	9.3	-0.08
		19	9.57	3.4	8.0	381.4	7.7	-0.12
		21	7.52	7.5	7.1	339.1	8.3	-0.08
		23	7.00	7.3	10.3	321.4	6.1	-0.08
		24	7.52	4.4	10.9	327.1	6.9	-0.12
		28	5.95	6.1	13.8	298.1	7.7	-0.04
		$\bar{x}$ SD	8.82 2.706	5.9 1.39	8.5 2.24	322.8 30.15	8.1 0.95	
	IV	15	8.29	6.7	5.0	241.4	6.3	-0.24
		16	10.33	3.9	7.1	266.2	7.7	-0.18
		20	7.14	3.9	5.7	258.6	7.3	-0.29
		22	6.52	6.7	7.1	282.4	6.3	-0.20
		$\bar{x}$ SD	8.07 1.676	5.3 1.62	6.2 1.05	262.4 17.03	6.9 0.71	
	I-IV	$\bar{x}$ SD	9.51 2.750	7.1 3.43	8.8 2.32	337.3 50.30	9.0 3.28	
GORCE		1	10.71	6.1	8.7	261.4	6.4	
		2	6.57	3.9	9.5	143.6	4.9	
		3	9.57	3.9	9.5	140.0	6.3	
		$\bar{x}$ SD	8.95 2.139	4.6 1.27	9.2 0.45	181.7 69.08	5.9 0.84	

contents among plants in the same sites were smaller than in the case of the remaining elements (Fig. 1). The plants least contaminated with cadmium were from the central parts of the forest complex. A wide range of lead contents was found: from 3.4 to 18.7 $\mu\text{g g}^{-1}$. In the western part of the forest, *Moehringia trinervia* accumulated an average of 14 $\mu\text{g g}^{-1}$ Pb, while in the eastern, 5.3 $\mu\text{g g}^{-1}$. The mean nickel content was about 9 $\mu\text{g g}^{-1}$. The most nickel was accumulated by plants collected from the deciduous (northern) part of the Niepołomice Forest (stands 24–28): from 10 to 14 $\mu\text{g g}^{-1}$. The zinc concentration was from 241 to 457 $\mu\text{g g}^{-1}$, copper from 6.1 to 23.7 $\mu\text{g g}^{-1}$. The highest Zn and Cu concentrations were found in the western parts of the forest. Their concentration in *Moehringia trinervia* decreased as the distance from the source of emissions increased.

The lead, zinc and copper contents in *Moehringia trinervia* sampled from Gorce were about two-fold lower, while the mean cadmium and nickel contents were comparable to those in *M. trinervia* from the Niepołomice Forest.

Four pollution zones of the Niepołomice Forest were identified on the basis of the composite index of contamination of *Moehringia trinervia* by heavy metals (Fig. 2, Table 1). Zone I encompasses the western part of the forest (index from

Fig. 2. Pollution zones of the Niepołomice Forest identified on the basis of heavy metal contamination of *Moehringia trinervia*. Zone I — index values > 0.26, II — from 0.02 to 0.15, III — from -0.02 to -0.12, IV — < 0.18

0.26 to 0.43). Zone II covers the northern part of the forest along the Drwinka river valley and the north part of the deciduous complex (index from 0.02 to 0.15). Zone III (index from -0.02 to -0.12) extends from the central part of the evergreen and the southern part of the deciduous forests. The eastern part of the forest was least polluted, constituting zone IV, which is most distant from the source of emissions (index from -0.18 to -0.20).

DISCUSSION

The degree of heavy metal accumulation by plants is characteristic for a given species (Ernst 1974). Some plants accumulate one or more heavy metals in exceptionally high amounts in their tissues, eg. *Thlaspi alpestre* spp. *calaminare* accumulates zinc (Ernst 1966), *Becium homblei*, copper (Wild 1969), representatives of the genus *Alyssum* accumulate nickel (Brooks and Radford 1978). These species grow on soils which are naturally rich in these metals. In areas polluted by industrial emissions, plants frequently accumulate one or more elements in elevated amounts. *Moehringia trinervia* belongs to this type of plants and is an efficient accumulator of cadmium.

The concentrations of all of the studied metals in *Moehringia trinervia* in the Niepołomice Forest exceeded natural levels (Kabata-Pendias and Pendias 1979), as well as being higher than in regions only slightly polluted by industrial emissions. This is in agreement with the levels of atmospheric pollution in this area. The high content of metals in other plant species in the Niepołomice Forest has also been determined by Grodzińska et al. (1987).

Vascular species take up metals in two ways: from the soil through their roots and from the atmosphere through their leaves. The soil, especially the floor cover in the Niepołomice Forest is highly polluted with heavy metals (Grodzińska et al. 1987). *Moehringia trinervia* is a plant with a shallow root system penetrating only the upper layers of the soil, those which are most polluted. The precipitation of metal-containing dust is very high in the Niepołomice Forest and is spatially differentiated (Garscia et al. 1984, Manecki et al. 1988). This is related to the pollutants emitted from over the Kraków agglomeration being blown over by the prevailing westerly winds. Cadmium is associated with the small particle dust which is carried for long distances and therefore, the pollution of the forest with this element is more uniform over its entire area. Other metals, associated with larger dust particles, fall closer to the source of emissions. The western part of the forest is therefore more polluted than its eastern part. The level of metals in *Moehringia trinervia* is in agreement with the degree of pollution of the forest floor and soil and with the distribution of dust precipitation over the Niepołomice Forest. The elevated nickel concentration in comparison with naturally occurring level in *Moehringia trinervia*, both in the Niepołomice Forest as well as in Gorce is related to the synergetic interaction of these metals (Kabata-Pendias and Pendias 1979).

The pollution zones identified on the basis of the *Moehringia trinervia* heavy metal content are in agreement with the results of other studies (K i s z k a 1977, M a k o m s k a 1978, G r a b o w s k i 1981). The western area of the Niepołomice Forest is always the most polluted by heavy metals, its central and eastern parts less.

Conclusions: *Moehringia trinervia* is a commonly occurring species in both deciduous and evergreen forest. The content of metals in this plant reflects their atmospheric and soil levels thus making this species a bioindicator of environmental pollution with these elements. *Moehringia trinervia* is an efficient cadmium accumulator.

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Moehringia trinervia (L.) Clairv. — wskaźnik skażenia środowiska metalami ciężkimi

Streszczenie

W czerwcu 1984 roku w Puszczy Niepołomickiej zebrano z 28 stanowisk pospolicie występującą na całym tym obszarze *Moehringia trinervia* (L.) Clairv. Sześć stanowisk zlokalizowanych było w części liściastej (północnej) Puszczy, pozostałe w jej części borowej (południowej). Zawartość Cd, Pb, Ni, Zn i Cu oznaczono spektrofotometrycznie aparatem Varian-Techtron po uprzednim zmineralizowaniu materiału roślinnego w mieszaninie kwasów HNO_3 i HClO_4 . Próby porównawcze zebrano w Gorcach.

Puszcza Niepołomicka oddalona o 10–35 km na wschód od Krakowa narażona jest na zanieczyszczenie związkami siarki i metalami ciężkimi. Transportowane są one z panującymi w tym obszarze wiatrami zachodnimi znad aglomeracji krakowskiej, a szczególnie z usytuowanego na wschodnich krańcach miasta kombinatu metalurgicznego.

Średnia zawartość metali ciężkich w *Moehringia trinervia* była duża. Największe stężenie metali stwierdzono w zachodniej części Puszczy, bliżej źródeł zanieczyszczenia, mniejsze w jej części wschodniej. Średnia zawartość kadmu w *Moehringia trinervia* z Puszczy Niepołomickiej wynosiła ok. $9.5 \mu\text{g g}^{-1}$, ołowiu — 7, niklu — 8.8, cynku — 337, miedzi — $9 \mu\text{g g}^{-1}$. W próbie porównawczej z Gorców stężenie Cd wynosiło ok. $9 \mu\text{g g}^{-1}$, Pb — 4.6, Ni — 9.5, Zn — 182, Cu — $6.3 \mu\text{g g}^{-1}$.

Summary index of pollution calculated for 5 elements (Cd, Pb, Ni, Zn i Cu) allowed to distinguish four zones in the Niepołomickie Forest. Zone I covered the western part of the forest, most heavily loaded with heavy metals (index value from 0.26 to 0.43). Zones II and III in the central part of the forest were moderately polluted with metals (index value respectively from 0.02 to 0.15 and from -0.02 to -0.12). Zone IV, which covered the eastern part of the forest, was least loaded with metals (index value from -0.18 to -0.29).

Moehringia trinervia is a strong accumulator of cadmium, its average level was in the parts of the forest 9 $\mu\text{g g}^{-1}$. This is a value many times higher than the level considered natural. In comparative tests the cadmium concentration in *Moehringia trinervia* was also very high.