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Input of heavy metals to the forest floor as the result of zinc smelter pollution in southern Poland

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Abstract. The aim of this study was to assess the impact of zinc smelter on heavy metals concentration in the litter fall collected from three different sites in Olkusz Forest located in southern Poland. Furthermore the study was designed to investigate the input of these metals to the forest floor. Three forest areas Podlesie I and Podlesie II located 3 and 4 km south-east from Bukowno zinc smelter and Cegielnia situated 6 km north-east from the smelter were selected. At the beginning of September 2006 five litter traps were set at each site. The quantity of litter fall, along with percentage composition of each species, were estimated for an area of 1m². The concentration of Cd, Pb, Cu, Zn and Fe in the litter fall and leaves of four main tree species were analysed. The input of these metals to the forest floor were determined. The input of cadmium ranged from 204 µg m² at Cegielnia to 1340 µg m² at Podlesie I. The input of lead was higher than cadmium and varied from 1031 µg m² at Cegielnia to 3252 µg m² at Podlesie II. The input of zinc and iron were about 10 times than cadmium and lead. The less input of all investigated metals was noticed in control site located at WNP. for those metals. The high input of heavy metals to the forest floor may have negative effects on investigated part of Olkusz forest ecosystem.

Key words: zinc smelter, heavy metals, litter fall, input, forest floor

Introduction

In the last two decades of 20th century industrial pollution and environmental degradation in Poland were one of the highest in Europe. The situation has improved considerably during last fifteen years (Nowicki 1993, Environment 2011). Quite new problem are the urban pollution, heavy traffic and low emission. Still the potentially adverse effect of air pollution on the natural environment is expected close to industrial sources. Generally such problems are in Śląskie, Dolnośląskie, Małopolskie, Łódzkie and Wielkopolskie districts (Environment 2011). Bukowno zinc smelter located in Małopolska district in Southern Poland belongs to one of largest in country. In 1995 smelter emitted 9600 kg of zinc, 5372 kg of lead and 511 kg of cadmium. Since 1995 emission decreased and in 2006 reached 1754 kg of zinc 34 kg of lead and 4 kg of cadmium (Pietruszewska 2007). Olkusz Forest situated in the western part of Małopolska district for a long time has been affected by industrial pollution from Bukowno zinc smelter and Upper Silesia Industrial Region. The effect of air pollutants on Olkusz Forest ecosystem has been studied

during the past ten years. Some results of this investigation, concerning heavy metal accumulation in small mammals, transplanted lichens and tree leaves shows contamination of this area. Also histopathological damage on rodents tissues, effects on population of invertebrates, and soil processes were also studied (Damek-Poprawa and Sawicka-Kapusta 2003, Białońska and Dayan 2005). The aim of this study was to estimate heavy metals concentration in the litter fall and the inputs of these metals to the forest floor that were due to air pollution from zinc smelter.

Material and Methods

Three forest areas in Olkusz Forest located in different distance from Bukowno zinc smelter and control site in Woliński National Park were selected. Two sites: Podlesie I and Podlesie II were located respectively 3 and 4 km south-east from Bukowno zinc smelter 3 and 4 km respectively and one: Cegielnia was situated 6 km north-east from the smelter. Control site was chosen in Wolinski National Park located in north-western part of Poland (Dudzik et al. 2010) At the beginning of

September 2006 five litter traps were set at each site. Traps were constructed as 1m² frames, made of wood with nylon net (whole size:1/1 mm) bottom. After two months of exposure the litter was collected and sorted into different tree species. The quantity of litter fall, along with percentage composition of each species, were estimated for each of 1m² trap. The input of litter and heavy metals (in ug or mg m²) to the forest floor were evaluated. The concentration of Cd, Pb, Cu, Zn and Fe in the litter fall and in leaves of *Quercus robur*, *Betula pendula*, *Fagus sylvatica* and *Pinus sylvestris* were determined. Dry samples were wet digested in a 4 : 1 mixture of nitric and perchloric acid and the concentration of heavy metals (Cd, Pb, Cu, Zn and Fe) was analysed using atomic absorption spectrophotometer PerkinElmer AAnalyst 800 with graphite furnace for Cd, Pb, Cu and with flame for Zn and Fe (Damek-Poprawa and Sawicka-Kapusta 2003). Reference material (SRM 1573A) were also analysed. The recovery ranged from 98.8% to 105.1%. Data are presented in µg g⁻¹ dry weight. One way analyses of variance and post hoc Tukey test were used to determine the statistical differences in heavy metal concentration in the litter fall and metal input to the forest floor between sites.

Results and Discussion

Table 1 show the amount of litter input of different tree species at each investigated sites. *Betula pendula*, *Fagus sylvatica*, *Quercus robur* and *Pinus sylvestris* were

present at all study sites in Olkusz Forest. Silver birch was not present at control area in Woliński National Park. Scots pine as the dominant tree at Cegielnia (25.7%). European beech was the dominant species at two sites at Podlesie II (60.6%) and Podlesie I (33.7%). At control area also the dominant species was European beech (62.7%). The average litter fall ranged from 86.4 g m⁻² at Cegielnia to 183.5 g m⁻² at Podlesie I. The highest litter fall 283.6 g m⁻² was noticed at control site (Table 1).

Heavy metals concentration in the litter fall showed differences between the investigated forest sites. The lowest concentrations of each metals were noticed at control area and ranged from 0.23 µg g⁻¹ for cadmium to 92 µg g⁻¹ for iron. Cadmium concentration in mixed leaves ranged from 1.29 µg g⁻¹ d.w. at Podlesie II to 7.30 µg g⁻¹ d.w. at Podlesie I. Statistically significant differences in cadmium concentration were found between each sites. Statistically highest lead concentration (18.93 µg g⁻¹) from the others was found in the litter fall from Podlesie II. (Table 2) Zinc concentration (145 µg g⁻¹) in the mixed leaves from Podlesie II was significantly lower than at Cegielnia and Podlesie I. Statistically highest iron concentration in the litter fall than in the two other sites was detected at Cegielnia (Table 3). Cadmium input to the forest floor ranged from 204 µg m⁻² at Cegielnia to 1340 µg m⁻² at Podlesie I. Statistical significant differences was found between Podlesie I and two other forest sites. The levels of lead input to the forest floor were significantly

Table 1. Average composition of litter fall in Olkusz Forest sites and in Woliński National Park (WNP) in 2006 [g and (%) of different species].

Species	Cegielnia	Podlesie I	Podlesie II	WNP (control)
Sites				
<i>Betula pendula</i>	89.2 (20.6)	13.4 (1.5)	36.0 (4.2)	-
<i>Fagus sylvatica</i>	25.3 (5.8)	309.5 (33.7)	520.1 (60.6)	888.7 (62.7)
<i>Quercus robur</i>	16.6 (3.8)	83.2 (9.1)	18.5 (2.3)	340.6 (24.0)
<i>Pinus sylvestris</i>	111.1 (25.7)	116.3 (12.7)	242.3 (28.2)	188.8 (13.3)
<i>Quercus rubra</i>	135.5 (31.4)	-	-	-
<i>Populus tremula</i>	3.9 (1.0)	356.8 (38.9)	-	-
<i>Padus avium</i>	29.1 (6.7)	10.2 (1.1)	-	-
<i>Larix decidua</i>	9.0 (2.1)	19.6 (2.1)	37.3 (4.2)	-
Others species	12.5 (2.9)	8.3 (0.9)	4.6 (0.5)	-
Σ [g]	432.2	917.3	858.8	1418.1
\bar{X} [g·m ⁻²]	86.4	183.5	171.8	283.6

different between all sites and ranged from 1031 $\mu\text{g m}^{-2}$ to 3252 lead $\mu\text{g m}^{-2}$ (Table 2). Input of zinc to the forest floor ranged from 25 mg m^{-2} in Podlesie II to 96 mg m^{-2} in Podlesie I. Input of this metal to the forest floor differed significantly between the sites in Olkusz Forest. The similar input of iron to the forest floor was in Podlesie I (76 mg m^{-2}) and Podlesie II (77 mg m^{-2}). These values were statistically higher than those found in Cegielnia (47 mg m^{-2}) (Table 3). The input of zinc and iron were about 10 times than cadmium and lead. The less input of all investigated metals was noticed in control site located at WNP. Generally the highest input of heavy metals to the forest floor were found in

sites located close to Bukowno zinc smelter. The input of the same heavy metals to the forest floor at sites impacted by Cracow conurbation in years 1998-2000 and in Ratanica catchment was lower than those found in Olkusz Forest (Grodzińska and Laskowski 1996, Sawicka-Kapusta et.al. 2003). Our findings suggest that input of heavy metals to the forest floor in Olkusz Forest which is very high may have several negative effects on the forest ecosystem by affecting soil microorganisms, organic matter decomposition and other soil biological processes (Laskowski et al 1993, Berg and Laskowski 2006).

Table 2. Average biomass of litter ($\text{g}\cdot\text{m}^{-2}$), cadmium and lead concentrations ($\mu\text{g}\cdot\text{g}^{-1}$ d.w.) in mixed leaves, and input of these metals to the forest floor in different sites in Olkusz Forest and in Woliński National Park (WNP).

Sites	Average biomass of litter	CADMIUM		LEAD	
		Concentration in mixed leaves $X \pm SE$	Input to the forest floor $[\mu\text{g}\cdot\text{m}^{-2}]$	Concentration in mixed leaves $X \pm SE$	Input to the forest floor $[\mu\text{g}\cdot\text{m}^{-2}]$
Cegielnia	86.4	2.36 ± 0.11^{a1}	204 ± 10^{a1}	11.93 ± 1.16^{a1}	1031 ± 99^{a1}
Podlesie I	183.5	7.30 ± 0.34^{b1}	1340 ± 63^{b1}	13.60 ± 0.91^{a1}	2496 ± 166^{b1}
Podlesie II	171.8	1.29 ± 0.20^{c1}	222 ± 20^{a1}	18.93 ± 1.70^{b1}	3252 ± 169^{c1}
WNP (control)	283.6	0.23 ± 0.03^2	65 ± 9.1^2	0.99 ± 0.01^2	281 ± 1.2^2

^{a,b,c} - the different letters indicate statistical differences between Olkusz Forest sites ($p < 0.5$)

^{1,2} - the different number indicate statistical differences between control and Olkusz Forest sites ($p < 0.5$)

Table 3. Average biomass of litter ($\text{g}\cdot\text{m}^{-2}$), zinc and iron concentrations ($\mu\text{g}\cdot\text{g}^{-1}$ d.w.) in mixed leaves, and input of these metals to the forest floor in different sites in Olkusz Forest and in Woliński National Park (WNP).

Sites	Average biomass of litter	ZINC		IRON	
		Concentration in mixed leaves $X \pm SE$	Input to the forest floor $[\mu\text{g}\cdot\text{m}^{-2}]$	Concentration in mixed leaves $X \pm SE$	Input to the forest floor $[\mu\text{g}\cdot\text{m}^{-2}]$
Cegielnia	86.4	431 ± 16^{a1}	37 ± 1^{a1}	543 ± 22^{a1}	471 ± 2^{a1}
Podlesie I	183.5	521 ± 21^{a1}	96 ± 4^{b1}	412 ± 13^{b1}	76 ± 2^{b1}
Podlesie II	171.8	145 ± 22^{b1}	25 ± 2^{c1}	451 ± 22^{b1}	77 ± 2^{b1}
WNP (control)	283.6	23 ± 2^2	6 ± 0.5^2	92 ± 4^2	26 ± 1^2

^{a,b,c} - the different letters indicate statistical differences between Olkusz Forest sites ($p < 0.5$)

^{1,2} - the different number indicate statistical differences between control and Olkusz Forest sites ($p < 0.5$)

Conclusion

Our surveys showed that Olkusz Forest is still impacted by the Bukowno zinc smelter emissions. The high input of heavy metals to the forest floor may have several negative effects on the investigated forest ecosystem.

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