JOURNAL OF FOREST SCIENCE, *54*, 2008 (2): 64–72

A survey of forest pollution with heavy metals in the Natural Forest Region (NFR) Moravskoslezské Beskydy with particular attention to Jablunkov Pass

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ABSTRACT: A survey of forest nutrition was carried out in Natural Forest Region (NFR) No. 40 Moravskoslezské Beskydy. The reason for this survey was the gradually worsening state of forest stands in this region and especially in a part of it – in the Jablunkov Pass. Air pollution was the suspected cause of the unfavourable development. According to methodology established for the survey of forest nutrition, the samples of soil and assimilatory organs were collected at 375 sampling sites. The spatial distinctness of Jablunkov Pass was expressed on the basis of selected soil characteristics (quantity of organic material, exchangeable pH, content of total nitrogen, zinc, lead, chromium, cadmium) and of the contents of chemical elements (total nitrogen, magnesium, zinc, lead, chromium, cadmium) in two-years-old Norway spruce needles. These analyses were done by the software Statistica. The medians of concentrations of elements in two-years-old Norway spruce needles in the area of NFR except Jablunkov Pass are: Zn – 34, Pb – 0.71, Cd – 0.15 and Cr – 0.38 (mg/kg). In the area of Jablunkov Pass: Zn – 43, Pb – 12.1, Cd – 0.25 and Cr – 0.41 (mg/kg). Particular attention was paid to the content of heavy metals both in the whole area of NFR and in the area of Jablunkov Pass particularly. The spatial homogeneity is disturbed by the influence of air pollution there. Markedly higher contents of zinc, lead and cadmium are found in the whole soil profile, in the case of chromium in the forest floor only. The distribution of heavy metal contents in the soil profile is influenced by the quantity and quality of organic matter and by the altitude of sampling sites. The higher values of medians of zinc, lead and cadmium contents are found in the area of the Pass. Chromium is an exception with the highest contents found in the southern part of NFR. The medians of concentrations of elements in the forest floor of Norway spruce stands in the area of NFR except Jablunkov Pass are: Zn – 70.6, Pb – 88.6, Cd – 6.4 and Cr – 0.69 (mg/kg). In the area of Jablunkov Pass: Zn – 103, Pb – 138, Cd – 8.8 and Cr – 1.02 (mg/kg). The spatial distinctness of the area around the Jablunkov Pass is confirmed by the evaluation of the data of forest nutrition survey. Particularly, it consists in the high contents of phytotoxic heavy metals. The exceptionally high pollution of this area can be a cause of the physiological weakness of trees with following attack of the honey fungus.

Keywords: Jablunkov Pass; heavy metals; forest nutrition survey; soil pollution

Serious damage to trees and even their mortality occurred in this relatively small region of Jablunkov Pass. The health status of forest stands changed and the leaf discoloration and dieback of trees occurred. The worst situation is in the north – in the eastern part of the region where groups of trees died. The violent development of honey fungus (*Armillaria melea* Quél.) observed in the stands resulted in a decrease in tree vitality, infestation by bark beetle and finally in the mortality of trees (Málek 1967). As the region concerned is under a long-lasting influence of pollutants from the North-Moravian industrial area, it may be possible that the development of *Armillaria* can be connected with the accumulation of pollutants in the soil, causing the restriction of root growth and nutrient uptake, as reported by Singh and Burke (1974) from Newfoundland.

Therefore a soil survey was undertaken to find whether there exist any significant differences between the region of Jablunkov Pass and the rest of the NFR. The soil survey was accompanied by needle analyses to detect differences in tree nutrition.

The question of occurrence of this damage is that it concerns a relatively small region. The soil survey and the results of leaf analyses in NFR 40: Moravskoslezské Beskydy (Moravian-Silesian Beskids) provided interesting results that may help to elucidate this problem. The investigation of element levels in the soil and in the needles and their interpretation by the application of statistical investigation seem to be a way of testing the eccentricity of plant nutrition and pollutant load of the Jablunkov Pass area.

The results can be used as the basis for the next treatment of affected stands.

METHODS

Study site

The NFR of Moravskoslezské Beskydy is a part of the outer Carpathian Arc.

The size of the forested area in the NFR is 62,008 ha. The region is situated between lat. 49°24' and 49°41'N, and between long. 18°01' and 18°51'E (ÚHÚL 2000). The bedrock is built of sandstone of godul an istebnian layers and the dominant soil type is Eutric Cambisol (Němeček et al. 2001). The potential natural vegetation of this region is generally represented by the *Festuco glandulosae-Fagetum* in the Silesian Beskids and in the north-eastern and in the western part more often by the *Dentario-eneaphylli-Fagetum* and *Festuco-Fagetum*. The fragments of *Calamagrostis villosae-Fagetum* (Culek 1996) are characteristic of the highest locations. The climate is typical of the temperate zone. Mean annual precipitation ranges from 900 mm to 1,377 mm, and mean annual temperature oscillates between 2.3°C and 7.8°C. Average temperature during the vegetation period is between 9.6°C and 13.8°C (ÚHÚL 2000).

The Jablunkov Pass is a mountain pass in the Moravskoslezské Beskydy Mts., located in the north of the NFR at the altitude of 553 m above sea level, near the frontier with Poland and Slovakia. This area is exposed to the greatest pollution because of the geographic exposition to the industrial area of Northern Moravia and the important transport routes leading throughout the area.

Methods of soil survey

The sampled sites were chosen in accordance with methodology established by Central Institute for Supervising and Testing in Agriculture (ÚKZÚZ) in Brno (Zemánek et al. 1992). The goal of the survey is to inform about the levels of plant nutrients in the assigned region so that it is focused on the most widespread management set of stands. 375 delivery points were situated all over the whole NFR, including 89 sites in the area of Jablunkov Pass. The points were stabilized by the colour sign on the tree in terrain and geodetically by the GPS system.

The main species in the area are Norway spruce (*Picea abies* [L.] Karst.) and European beech (*Fagus sylvatica* L.) accounting for 75% and 20% of the basal area, respectively. Forest floor samples were collected from 375 spruce, beech and mixed stands. The stands with the species composition of either spruce or beech more than 60% were taken into account. There were 163 spruce and 42 beech stands in the whole NFR, and 53 spruce and 22 beech stands in the Pass area. Holorganic subhorizons (L, F, H) were collected together from the square of 25 × 25 cm from the forest floor. Large material over 20 mm in diameter and macroscopic living material (vegetation, mosses, fungi, roots, etc.) were removed from the samples. Mineral soil samples were collected from two pedogenetic horizons involving the root zone, important for assessing the nutrient ability of soils. Both the holorganic and the mineral soil samples were stored at 2°C prior to analysis. The sampled soils were classified according to the Czech Taxonomic Soil Classification System (Němeček et al. 2001) as Eutric-Cambisol. The sampling was carried out during two surveys conducted in 2004 and 2005, in September and October, out of the vegetation season. Needle samples were taken from the isolated parts of the trees from the upper third of the crown. The current year and two-years-old needles were taken. Prior to the chemical analysis, the needles were dried without previous washing out.

Methods of chemical analysis

Soil samples

Determinations of pH_{H_2O}, pH_{CaCl_2} were done in air-dried soil samples according to ISO 10390:2005, which specifies the routine determination of pH using a glass electrode in a 1:5 suspension of soil in water (pH in H_2O) or in 0.01 mol/L calcium chloride solution (pH in $CaCl_2$). Parameters N_{tot} and C_{tot} were determined using near infrared spectroscopy (FOSS NIRSystem 6500). Digestion with 2M HNO_3 was used for the determination of acid extractable (so called) total contents of elements (P, K, Ca, Mg, Fe, Al, Cd, Cu, Pb, Zn). The soluble elements in the extracts were determined by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). Determination of cation exchange capacity (CEC)

Table 1. Heavy metals in forest floor – median of contents (mg/kg)

NFR	01	11	14	16	25	27	40	Jablunkov FD
Lead	72	80	58	63	140	104	98	119
Zinc	45	45	35	41	46	47	77	110
Chromium	6	8	12	10	7	6	7.5	8.8
Cadmium	39	0.37	0.23	0.29	0.46	0.49	0.78	1.2

NFR – Natural Forest Region, FD – Forest District

according to Mehlich was done by $BaCl_2$ (extract 1) saturation (pH = 8.1) followed by $MgCl_2$ (extract 2) replacement. On the basis of results obtained from titration of extract 1 and measurement of Ba concentration in extract 2 we can determine the values of H^+, S, T, V (Zbíral et al. 1997).

Plant samples

Wet digestion with H_2SO_4, Se and H_2O_2 was used for determination of N, P, K, Ca, Mg, Na, followed by methods of detection: titrimetric method for N (Kjeltec, Tecator), spectrophotometry for P (Spekol 11), flame emission for K and AAS-Flame for Ca, Mg.

Dry ashing and uptake in HNO_3 were used for determination of B, Zn, Mn, Fe, Al, Cu, Cr, Ni, Pb, Cd. The contents of the elements were measured using ICP-AES technique (B, Zn, Mn, Fe, Al, Cu, Cr, Ni) and AAS-flame with ACT (atom concentrator tube) for Cd, Pb. Wet digestion with HNO_3 and H_2O_2 was used for S followed by ICP-AES as the technique of detection (Zbíral 1994).

Methods of statistical analysis

Exploratory statistical analysis involves the examination of mean values, coefficients of variation, maximum and minimum values, and coefficients of skewness and kurtosis. These analyses were done by the software Statistica. Because the data were not normally distributed in most cases, nonparametric correlations according to Spearman were calculated.

RESULTS

As the industry centre is represented especially by heavy metallurgy, the main attention was paid to the concentration of heavy metals Pb, Zn, Cr and Cd. It was possible to compare the results with the results in some other NFR in the country (Table 1).

01 Krušné hory Mts. – since the middle of the nineteenth century a heavily polluted area, pollutants originating esp. from lignite mining, processing and burning and from oil refineries. In Middle Ages a centre of ore mining and processing.

11 Český les (Bohemian Forest)

14 Novohradské hory Mts.

16 Českomoravská vrchovina Upland
– all three NFR in the south of the country, without industrial pollution and also relatively less affected by automobile emissions.

25 Orlické hory Mts. – a substantial part of Norway spruce stands at high locations of mountains was destroyed as a result of high SO_2 contents in the 1980s. But there is also an evidence of the influence of other pollutants there.

27 Jeseníky Mts. – an area without significant direct air pollution influence in the past, but with rela-

Table 2. Median of contents of elements under Norway spruce stands (mg/kg)

Horizon	Organic material	N_{tot} (%)	pH_{H_2O}	Ca	K	Mg	Zn	Pb	Cr	Cd
The area of NFR 40 except Jablunkov FD										
02	70.1 (t/ha)	1.40	3.4	2,810	1,040	481	70.6	88.6	6.4	0.69
07	8.5 C_{ox} (%)	0.45	3.9	118	94	32	14	96	3.8	0.17
08	3.5	0.19	4.3	43	48.5	12.5	10	24	4.2	0.09
The area of Jablunkov Pass										
02	59.9 (t/ha)	1.31	3.4	2,600	1,050	620	103	138	8.8	1.02
07	7.5 C_{ox} (%)	0.34	4.0	127	82.5	32	17	107	4.6	0.24
08	2.8	0.14	4.3	52	41	12	11	19	3.8	0.09

Table 3. Median of concentrations of elements under beech stands (mg/kg)

Horizon	Organic material	N_{tot} (%)	pH_{akt}	Ca	K	Mg	Zn	Pb	Cr	Cd
The area of NFR 40 except Jablunkov FD										
02	66.8 (t/ha)	1.51	4.0	5,415	1,420	870	101	83	6.7	0.98
07	8.1 C_{ox} (%)	0.37	4.1	182	113	43	20	129	3.9	0.23
08	3.7	0.25	4.4	64	50	13	14	25	3.7	0.15
The area of Jablunkov Pass										
02	63.7 (t/ha)	1.42	4.0	5,770	1,390	959	121	94	8.0	1.28
07	7.4 C_{ox} (%)	0.32	4.2	320	120	51	31	158	4.4	0.55
08	2.8	0.15	4.4	65	53	14	12	24	4.0	0.14

02 – humus layer, 07 – layer enriched with humus substances between the organic horizon and the mineral soil, 08 – mineral soil to 30–40 cm

tively high acid deposition resulting in considerable soil changes and yellowing of Norway spruce stands.

In this comparison the enrichment of the humus layer in NFR 40 and especially in the Jablunkov Pass is remarkable in respect of zinc and cadmium contents, the median of the contents in these areas is higher than in any other NFR, and the level of Cr and Pb is also very high.

The results of more detailed analyses are presented in Tables 2 and 3 and discussed in the following text.

Quantity of organic material, exchangeable pH and macronutrient levels

There are not any great differences in the amount of organic material between spruce and beech stands or between the stands in the whole NFR and in the Jablunkov Pass. The humus layer is less acid in beech stands, but this is not the case in the mineral soil. The organic layer under beech also has a substantially higher concentration of calcium and magnesium, and there are only small differences in respect of potassium. But as far as the Jablunkov Pass is concerned, no heterogeneity in the macronutrient levels in the whole NFR could be found.

Heavy metals in soils

Lead

The lead pollution in the area of the Pass is significantly and spatially exceptional with regard to the whole area of NFR. The supposed value of the critical pollution 150 mg/kg (Tyler 1992) is exceeded in 40% of samples in the area of the Pass while in the area of NFR 40 except the area of Jablunkov Pass in 20% of samples (Fig. 1).

High contents are found in the uppermost mineral horizon in forest stands along the Jablunkov Pass especially under beech. The contents here exceed the values found in the horizons of forest floor (Fig. 2). The amounts of lead in spruce stands in the forest floor horizon and the uppermost mineral horizon are significantly higher ($P < 0.05$).

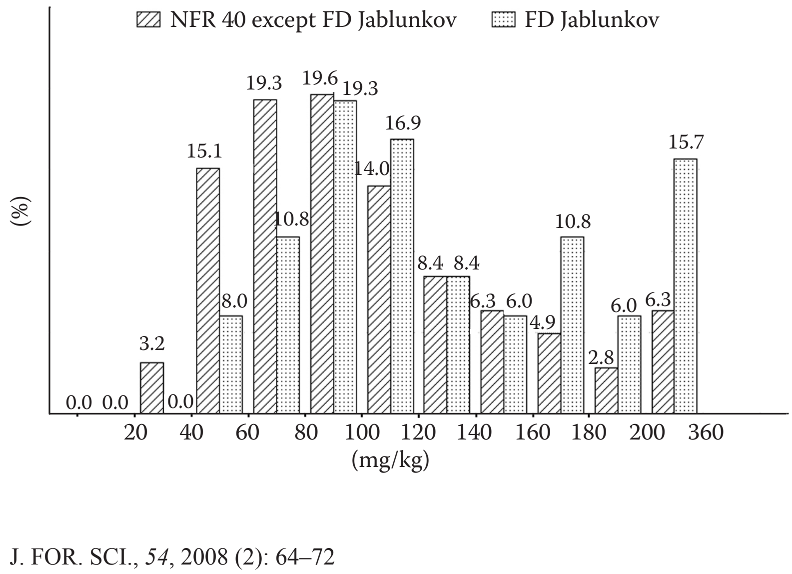

Fig. 1. Frequency distribution of lead content in forest floor

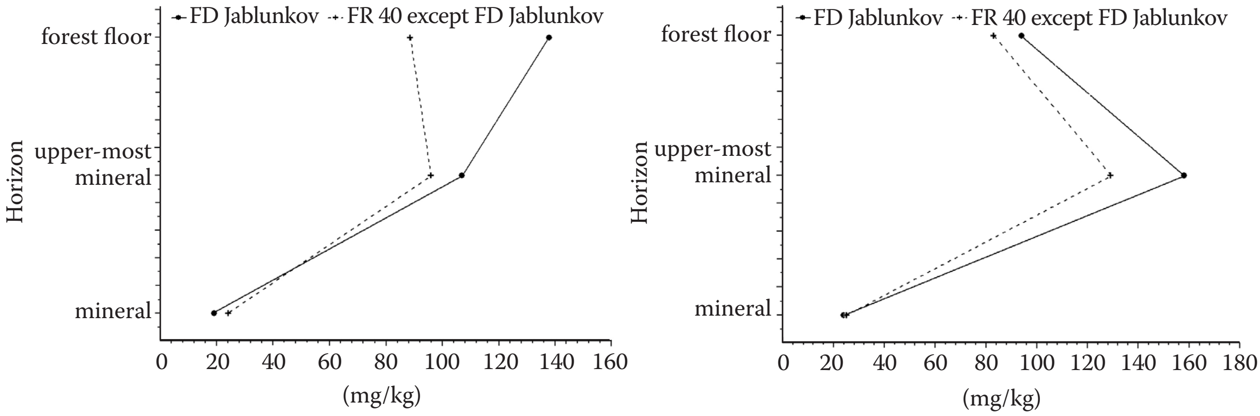

Fig. 2. Content of lead (median) (mg/kg) in soil profiles of spruce (left) and beech (right) stands

Zinc

The contents of zinc are higher in the area of Jablunkov Pass than in the remaining area of NFR (Fig. 3). Its higher contents are evident in the uppermost mineral horizon along the Jablunkov Pass. The contents reach the value of 100 mg/kg rarely there. Similar spatial pollution can be seen in the mineral horizons. The contents of zinc are higher ($P < 0.05$) in beech stands compared to spruce stands, especially in the forest floor (Tables 2 and 3).

Chromium

The highest contents of chromium in the forest floor are found in the northern part near the industrial agglomeration of Northern Moravia, the supposed source of pollution. The contents here are higher by 20% than in the whole NFR. There is no significant difference between spruce and beech stands (Fig. 4).

Cadmium

In the case of cadmium, evident higher pollution is detected in the area of the Jablunkov Pass in comparison with the remaining area of NFR. The spatial distinctness of distribution of this element in the Jablunkov Pass is confirmed in the forest floor ($P < 0.05$) as well as in the mineral horizons ($P < 0.05$). The contents in the Pass exceed the contents in the whole NFR by 40%. The soil profiles in beech stands have higher amounts ($P < 0.05$) in the uppermost mineral horizon in the profile (Tables 2 and 3).

In the case of zinc, lead and cadmium we found higher contents in soils in the area of the Pass. This is confirmed by the highest values of the median: Zn = 103 mg/kg in contrast with 70.6 mg/kg in spruce stands and 121 in contrast with 101 mg/kg in beech stands in the NFR, Pb = 138 mg/kg in contrast with 88.6 mg/kg in spruce stands and 93.6 in contrast with 83.3 mg/kg in beech stands in the NFR, Cd = 1.02 mg/kg in contrast with 0.69 mg/kg in spruce stands and 1.28 in contrast with 0.98 mg/kg in beech stands in the NFR. But in the case of chromium, the highest contents were found in the southwestern part of NFR.

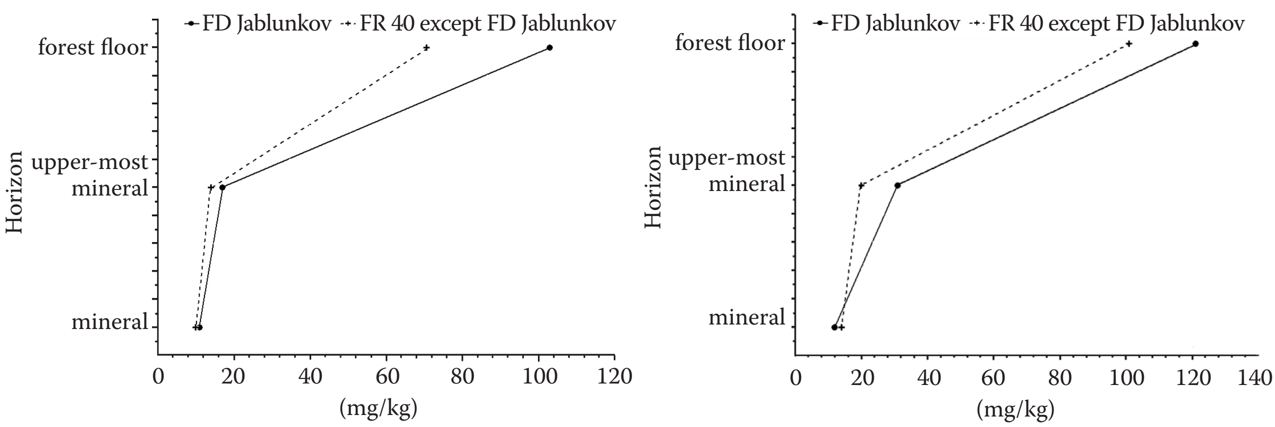

Fig. 3. Content of zinc (median) (mg/kg) in soil profiles of spruce (left) and beech (right) stands

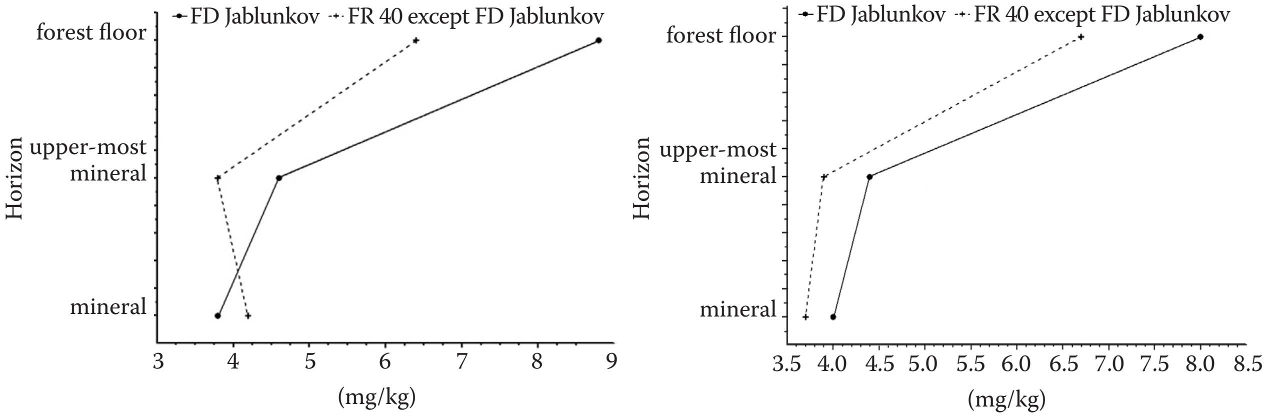

Fig. 4. Content of chromium (median) (mg/kg) in soil profiles of spruce (left) and beech (right) stands

RESULTS OF LEAF ANALYSES

The results of analyses of spruce needles and beech leaves are presented in Table 4. As far as the macronutrients are concerned, the median of the results is in accordance with the limits of sufficient nutrition for both tree species in the whole area of NFR 40 and Jablunkov Pass as well. There are no significant differences in the composition of spruce needles and beech leaves between the Jablunkov Pass and NFR. Differences in the composition of needles and leaves document higher demands of beech for nutrition. More pronounced differences in the heavy metal concentrations between both areas could be detected. Both in spruce needles and beech leaves the Pb, Zn, Cr and Cd contents are higher in the forest stands in Jablunkov. However, the analysis of relationships between the individual elements indicated only the following positive correlations:

Ca × Mg $r = 0.90$, Ca × Cd $r = 0.59$,
Ca × Zn $r = 0.84$

In the most polluted area, these correlations are even stronger:

Ca × Mg $r = 0.90$, Ca × Cd $r = 0.79$,
Ca × Zn $r = 0.91$

DISCUSSION

The goal of the survey – to point out the exceptionality of the area of the Jablunkov Pass, was supported by recent findings. The reserve of heavy metals is significantly affected by anthropogenic disturbances especially in the surveyed area (Markert et al. 1996). We focused on the selected elements – lead, zinc, chromium and cadmium. These metals are permanently released into the environment in large quantities and show a different environmental behaviour (Siegel 2002). The emissions from the industrial area of Northern Moravia have a very diversified composition as they are produced by metallurgy, chemical industry, power plants and traffic as well. Natural Forest Region 40 Moravskoslezské Beskydy is immediately influenced by them. In connection with the unfavourable development in the forests of the NFR, two main questions have to be answered. First, whether the contents of the respective elements are really extremely high in comparison with the other NFR in the country. Second, whether the contents are high enough to have an adverse effect on forest trees. As far as the first question is concerned, the deposition of lead (10–15 mg/m^2/yr), as moni-

Table 4. Median of contents of elements in both compared stands (mg/kg)

	N (g/kg)	P	K	Ca	Mg	Pb	Zn	Cr	Cd
The area of NFR 40 except Jablunkov FD									
Norway spruce*	14.1	1,200	6,263	5,303	829	0.71	34	0.38	0.15
Beech	22.0	1,400	9,765	8,392	1,420	2.20	42	0.55	0.27
The area of Jablunkov Pass									
Norway spruce*	14.0	1,131	6,432	5,409	819	1.10	43	0.41	0.25
Beech	21.8	1,300	9,599	9,159	1,365	3.00	46	0.77	0.29

*Two-years-old spruce needles

Table 5. The accumulation of elements (mg/kg) in the humus layer

Element	NFR Moravskoslezské Beskydy	Slovak forests*	Finnish forests
Pb	121.70	61.40	32.8
Cd	0.89	1.140	0.4
Cr	26.20	28.40	7.9
Zn	65.70	108.00	49.5

*111 samples from a network 16 × 16 km all over the country

tored by the Czech Hydrometeorological Institute (ČHMÚ), is not as high as in some parts of forests in Northern Bohemia. And the Cd deposition in the region (0.5–0.75 mg/m^2/yr) does not reach the level of pollution in the polluted regions of the country. As well as zinc, this pollutant is deposited in amounts similar to other polluted areas (ČHMÚ 2004). Chromium is not monitored in the monitoring network of ČHMÚ. Nevertheless, the results of biomonitoring – analyses of mosses (Uhlířová, Hejdová 1999) indicate this region as a very polluted and highly influenced one with respect to lead, cadmium and chromium. The contents of zinc are also very high.

A study of heavy metal distribution conducted in the forests of the north-western part of Slovakia, not far from the area of Moravskoslezské Beskydy, documented an accumulation of elements in the humus layer (Lobe et al. 1998). The sources of pollution in both areas seem to be the same.

But relatively very high contents of heavy metals are reported also from other parts of Slovakia (Maňkovská 1997). In samples from the humus layer the following mean concentrations were analyzed (Table 5).

Comparing these results with the findings in the Jablunkov Pass, the organic layer in Slovakia is very rich especially in chromium and zinc, and also in cadmium and lead. It is due not only to air pollution but also to the influence of bedrocks, rich in minerals containing these elements. Substantially lower are the contents in humus samples from the monitoring network (ca 3,000 points) in Finnish forests (Tamminen et al. 2004).

Such contents can be considered as an example of natural background contents.

The analyses of organic horizon in forest stands of NFR 40 indicate an intensive impact of the above-mentioned pollutants, nevertheless, not an extraordinarily strong one. If we calculate the amounts of lead, zinc and cadmium accumulated in the humus layer (using the median of contents in Norway spruce forests), with the mentioned amount of deposition, then it corresponds to a deposition of 8–10 years in the case of Zn and Cd and more than 50 years in the case of lead. An intensive accumulation of lead in the organic layer under forest stands was found also in other soil surveys (Deutscher Waldbodenbericht 1997; Materna 2002). Lead in the solid phase of soil is adsorbed at a considerably higher rate in the presence of organic matter. It means that the anomalous value of the median is caused by the high pollution and the presence of humus in the uppermost mineral horizon in the area of the Pass. Pb content in the humus layer is therefore a better indicator of environmental pollution than Cd or Zn content. A high content of Cr is found in the area of the Pass in the forest floor. However, the found contents of this element are substantially lower than in other studies reported here. This different type of pollution by Cr is evident from the downward trends of Cr contents down to the profile depth in the area of Jablunkov Pass and, in contrast, the upward trends found in the whole area of NFR. It may indicate different sources of chromium, the chromium of geological origin which participates, besides the air pollution, in the total content. In general, soil organic matter decreases mobility and reduces bioavailability of heavy metals (Brümmer et al. 1986). On the other hand, the heavy metals accumulated in soil can subsequently be taken up by plant roots or be leached into groundwater (Lair et al. 2006).

According to the findings of Uhlířová and Hejdová (1999) the median of Pb, Zn and Cd contents in the Jablunkov Pass corresponds to a medium class of pollution of the humus layer. 71.3% of samples belong to this category in the case of lead, and 10.2 and 96.3%, respectively, of all samples in the case of Cd and Zn in the whole country.

The results of needle analyses conducted in Norway spruce stands on old spoil banks in the Black Forest (Schwarzwald) are very interesting in relation to our findings. The contents of lead, zinc and cadmium are higher there than the contents from the Jablunkov Pass. This corresponds to the very high amounts of these elements in the soil. Nevertheless, remarkable is the fact that the trees have no visible symptoms of malnutrition, although their increment is limited. The colour of needles is normal (Hurrle 1981).

There is no reliable information on the toxicity of any of the elements to the European tree species. Tyler (1992) derived the toxicity limits from the influence of selected elements on the biological activity in Swedish raw humus layers, these limits are not therefore relevant to the vitality of forest trees.

The nutrition level in spruce and beech stands seems not to be influenced by the presence of increased concentrations of heavy metals under study (Pb, Zn, Cd and Cr). However, this does not mean that the stands are not negatively influenced by air pollution. There are numerous other pollutants in the environs of such an industrial centre as in Northern Moravia, for example other metals such as copper, manganese, iron, various compounds of fluorine, and sulphur dioxide and other sulphur compounds, etc. Such a complex of pollutants can be the cause of decreased vitality of forest trees and their greater susceptibility to the honey fungus impact.

CONCLUSION

The results of the survey of forest nutrition in the NFR Moravskoslezské Beskydy confirmed the supposed high contents of heavy metals in the area of the Jablunkov Pass. The industrial pollutants affect the soil environment. But the results of leaf analyses did not confirm a direct impact of the above-mentioned elements on the tree nutrition.

Nevertheless, this does not exclude that the whole complex of pollutants, including many other elements and compounds, could contribute to the undesirable vulnerability of trees and development of honey fungus.

Acknowledgements

The authors would like to thank Jan Materna for his expert assistance with this paper.

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Received for publication September 11, 2007
Accepted after corrections December 5, 2007

Průzkum znečištění lesa těžkými kovy v přírodní lesní oblasti Moravskoslezské Beskydy se zvláštním zřetelem na Jablunkovský průsmyk

ABSTRAKT: V přírodní lesní oblasti (PLO) č. 40 Moravskoslezské Beskydy byl proveden průzkum výživy lesa. Důvodem tohoto průzkumu je postupně se zhoršující stav lesních stanovišť v této oblasti, zvláště v její části – Jablunkovském průsmyku. V souladu s metodikou stanovenou pro průzkum výživy lesa byly na 375 odběrných místech odebrány vzorky půdních horizontů a asimilačních orgánů. Na základě vybraných půdních charakteristik (množství nadložního humusu, výměnná půdní reakce, obsahy celkového dusíku, zinku, olova, chromu a kadmia) a dále na obsazích chemických prvků ve dvouletých jehlicích smrku ztepilého (celkového dusíku, hořčíku, zinku, olova, chromu a kadmia) byla vyjádřena odlišnost oblasti Jablunkovského průsmyku. Pro hodnocení bylo použito výstupů statistického softwaru Statistica. Mediány koncentrací ve dvouletých jehlicích smrku ztepilého v celé PLO bez Jablunkovského průsmyku jsou: Zn – 34, Pb – 0,71, Cd – 0,15, Cr – 0,38 (mg/kg). V oblasti průsmyku: Zn – 43, Pb – 12,1, Cd – 0,25, Cr – 0,41 (mg/kg). Zvláštní pozornost je věnována obsahům těžkých kovů, a to jak v celé PLO, tak zvlášť v oblasti Jablunkovského průsmyku. Zde už je prostorová homogenita narušena imisními vlivy. Zřetelně vyšší obsahy zinku, olova a kadmia jsou zjištěny v celém půdním profilu, v případě chromu pouze v nadložním humusovém horizontu. Velikost obsahů těžkých kovů je ovlivňována množstvím a kvalitou organického materiálu i nadmořskou výškou odběrného místa. U zinku, olova a kadmia jsou v průsmyku zjištěny vyšší hodnoty mediánů obsahů. Výjimkou je chrom, jehož nejvyšší hodnoty jsou zjištěny v jižní části PLO. Mediány koncentrací v humusovém horizontu smrkových stanovišť v celé PLO bez Jablunkovského průsmyku jsou: Zn – 70,6, Pb – 88,6, Cd – 6,4, Cr – 0,69 (mg/kg). V oblasti Jablunkovského průsmyku: Zn – 103, Pb – 138, Cd – 8,8, Cr – 1,02 (mg/kg). Vyhodnocením údajů z průzkumu výživy lesa je potvrzena výjimečnost území kolem Jablunkovského průsmyku. Ta spočívá ve zvlášť vysokých obsazích fytotoxických těžkých kovů. Výrazně vysoké znečištění této oblasti těžkými kovy může být příčinou fyziologického oslabení stromů s následným napadením václavkou.

Klíčová slova: Jablunkovský průsmyk; těžké kovy; průzkum výživy lesa; znečištění půdy

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