ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 65 6 Number 1, 2017
https://doi.org/10.11118/actaun201765010051

METAL POLLUTION OF FOREST PHYTOMASS FROM URANIUM INDUSTRY IN CZECH REPUBLIC AND ITS ECOLOGICAL MANAGEMENT PERSPECTIVES

David Juřička[1], Libor Mikl[2], Marcela Muchová[1], Hana Cihlářová[1], Jan Hladký[3], Zdena Rosická[1], Jitka Novotná[1], Radka Frýzová[1], Martin Brtnický[3], Jindřich Kynický[1]

[1]Department of Geology and Pedology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Czech Republic, Zemědělská 1, 613 00 Brno, Czech Republic
[2]Institute of Vertebrate Biology, Academy of Sciences of the Czech Republic, Květná 8, 603 65 Brno; Masaryk University, Faculty of Science, Department of Botany and Zoology, Kotlářská 267/2, 611 37 Brno, Czech Republic
[3]Central European Institute of Technology, Brno University of Technology, Purkyňova 656/123, 612 00 Brno, Czech Republic

Abstract

JUŘIČKA DAVID, MIKL LIBOR, MUCHOVÁ MARCELA, CIHLÁŘOVÁ HANA, HLADKÝ JAN, ROSICKÁ ZDENA, NOVOTNÁ JITKA, FRÝZOVÁ RADKA, BRTNICKÝ MARTIN, KYNICKÝ JINDŘICH. 2017. Metal Pollution of Forest Phytomass from Uranium Industry in Czech Republic and Its Ecological Management Perspectives. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 65(1): 0051–0059.

The paper is focused on the issue of metals migration within the forest environment affected by deep mining of metals and the possibility how to immobilize them using an environment-friendly method. First, the paper presents the information about metal content in the tree leaves in alluvial recipients polluted by metals from uranium deep mining at Dolní Rožínka, the Czech Republic. X-ray fluorescence analysis of dried leaves results showed the increased content of Cu, Fe, Mn, Ni, Rb, Sr, Zn and U; it corresponds to the most seriously polluted areas in the world comparing with the scientific literature. However, statistically, we did not succeed to demonstrate in none of areas of interest the element heterogeneity between the upper, middle and lower streams segments. Element habitat homogeneity can be caused by current stand species composition where Picea abies L. dominates and this fact results in the negative impact on the soil pH since it is a primary factor of metals immobilization in the ecosystem and their transformation into toxic variations. Within the area of interest, there is demonstrated positive effect of reconstruction of forest stands, which are close to the dominating deciduous trees, especially Fagus silvatica L. This management change in the selected interested forest stands can result in Ca supply of up to 39 $kg.ha^{-1}$ from strictly natural sources, which might be a perspective alternative to liming.

Keywords: metals, forest, *Fagus silvatica*, *Picea abies* L., stream, pH

INTRODUCTION

The research is focused particularly on tree leaves analyses in alluvial environment affected by long-term uranium mining in the Czech Republic and proposing a relevant methodology how to immobilize pollutants in the environment using exclusively management modification and changing forest stand composition or applying afforestation of new suitable forest stands on non-forest land. Samples for further analyses were taken in the site with current mining activities within the mining area Rožná-Rozchody (deposit Rožná) and the mining area Olší-Drahonín (deposit Olší) where mining was terminated. The research provides the original information about metal content in phyto-mass; any similar research had not been realized so far in the uranium mining at Dolní Rožínka, the Czech Republic.

The mining on Rožná deposit started in 1957(Címala 1997); this deposit has been in continuous operation up to now: it is also the only uranium mine in operation in Central Europe (Government Decree no. 565/2007). The pollution recipient caused by uranium mining in Rožná deposit is found in the Nedvědička stream; in Olší deposit it is found in the Hadůvka stream. Waters of various origin sources, i.e. U, Ra, Cu, Zn, and Ni discharge into the Nedvědička; predominantly, it is treated water from the mine water decontamination plant and leachate from two sludge basins (Váša *et al.* 2015). The Hadůvka stream has been a recipient of treated mine water since 1996; that time, a pumping station and mine water treatment plant were constructed there.

Having finished the mining and flooded the mine in Olší locality, the groundwater flow vitalized, the Hadůvka water level increased and high uranium water concentration up to 2.2 $mg.l^{-1}$ occurred (Hájek and Koscielniak 1997).

The primary issue of mining sites and industrialized regions consists in pollutants deposits (Ianculescu *et al.* 2009), which might be affected by inappropriate forest tree species composition: metals are mobilized and transformed into a toxic shape (Hruška *et al.* 2009). Therefore, in this respect, the utmost importance is put on the forest ability to adjust soil as well as streams pH.

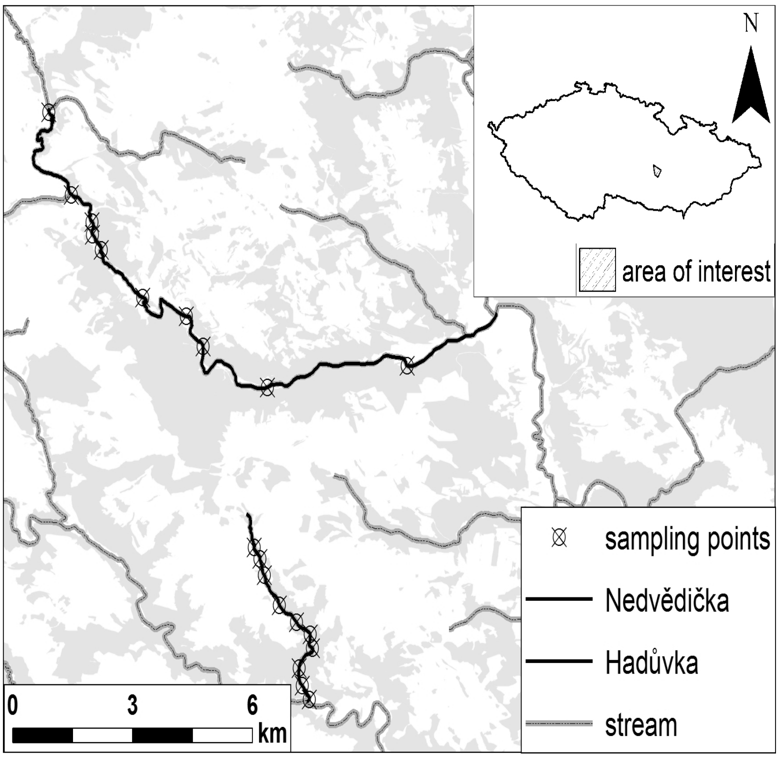
The acidic environment increases solubility and mobility of metals in soil and sediments, their toxicity increases and makes them available for plants: those are, in particular, Mn, Cr, Se, Co, Pb, As, Ni, Zn, U and Cu (Harter 1983; Sandifer, Hopkin 1996; Violante *et al.* 2010).In case of areas of interest, thus there are mobilized particularly Al, Cu, Ni, Zn and U.

Speaking about the prospective closing the Rožná mine, it is advisable to ensure the long-term sustainable ecosystem protection against heavy metals depositions resulting not only from groundwater outflow. This fact can be accomplished applying a relevant woody plants composition. Forest structure with dominating *Picea abies* L. cannot lead to improving the current situation (Souček and Tesař, 2008).

MATERIALS AND METHODS

The research is located in two deposit regions: Rožná-Rozchody (site 1 = Nedvědička stream) and Olší-Drahonín (site 2 = Hadůvka stream).

The streams Nedvědička and Hadůvka are of a stream type: they create the alluvial floodplain in a very limited range. The Nedvědička bedrock consists of amphibolites, gneiss, schists and migmatites. The geological bedrock of the Hadůvka valley consists of amphibolites, migmatites, gneiss (WMS map server, 2016); in the lower parts of the stream there are found syenites (own research). Their flow depends almost entirely on atmospheric



1: *The area of interest of Nedvědička (site 1) and Hadůvka (site 2) stream on the forest area background* precipitation (Váša *et al.* 2010). The average annual rainfall reaches 600–650mm (Tolasz 2007). The average spring temperatures fluctuate within the range of 6–7 °C, summer ones 13–14 °C, autumn 6–7 °C and winter –3 až –2 °C. The average Hadůvka annual flow equals 0.019 m3.s–1(Šenk 2001), and Nedvědička 0.212 $m^3.s^{-1}$ (Veselý 2006). The forest environment of areas of interest is made up of a commercial forest where coniferous species dominate, in particular, *Picea abies* L. (Úhúl 2016). The narrow strip along the Nedvědička and Hadůvka water course is covered with developed fast growing vegetation and ameliorative stands related to higher groundwater subsidies (in particular *Alnus glutinosa* L., *Acer platanoides* L.; personal observation).

Samplings for further analyses were carried out within the time interval October 2014 and 2015. The autumn sampling is represented by wide range of selection and higher concentrations of chemical elements present in samples (Tyler, Olsson 2006). There were sampled leaves from streamside stands, which accumulate high amounts of potential contaminants, metals. Sampled trees in the specific area can be classified as natural stands. The entire deciduous tree species found in the site 1 and site 2 (Fig. 1) streamside stand were sampled (*Aesculus hippocastanum* L., *Alnus glutinosa* L.,*Acer platanoides* L., *Acer negundo* L., *Acer pseudoplatanus* L.,*Carpinus betulus* L.,*Cornus sanguinea* L.,*Corylus avellana* L., *Fraxinus excelsior* L.,*Prunus avium* L.,*Quercus robur* L.,*Salix fragilis* L., *Sambucus nigra*. L., *Sorbus aucuparia* L.). The aim of research consists in assessing the vegetation impact on the catchment area as a whole and not only its segment represented by a particular species having specific requirements for its environment. The site 1 as well as site 2 is equally represented by 10 sampling points. In terms of site 1, samples were taken from 30 trees within 13,456 m stream segment of interest (443–365 m a.s.l.); considering site 2, samples were taken from 20 trees within 4,015 m stream segment of interest (412–367 m a.s.l.). The higher number of trees in site 1 is considered as a compensating factor in the large catchment area and longer Nedvědička stream.

The analyses were performed manually using ED-XRF (Energy Dispersive X-ray Fluorescence) spectrometer DELTA. The device uses the latest ED-XRF technology, 4 W X-ray tube, and 200μA current (max).The XRF method is widely used for environmental analyses. It offers accurate and fast analyses of organic material, soils and river sediments (Salminen *et al.* 2005; Zeng *et al.* 2013; Pouzar *et al.* 2006; Crompton 1996; International atomic energy agency 1997; Luke 1968; Yagi *et al.* 2013). Analyses were carried out using dry material. The mixed sample of one leave species was dried at 65 °C until the constant value (Zeng *et al.* 2013); after that it was crushed and homogenized. The measurement itself was conducted in an original disposable cuvette on a static structure.

The concentration differences of selected elements between studied locations (in individual stream segments) were evaluated using the generalized estimating equation (GEE), which is similar to the analogous generalized linear models (GLM) for data taken on the time scale and abnormal distribution (Zuur *et al.* 2009). The individual elements were analyzed using Gamma distribution with inverse link and correlation coefficient "ar1". The correlation coefficient was selected due to the fact the samples had been taken repeatedly along one-dimensional transect (Zuur *et al.* 2009).

RESULTS

The statistically significant difference (GEE) between the upper (sampling sites 1, 2 and 3), medium (sampling sites 4, 5, 6, and 7) and lower stream segment (sampling sites 8, 9 and 10) was not found out. Resulting from anomalous values occurring in spots, the environment of individual investigated localities is characterized as element-similar (Tab. I).

I: *Metals concentration in tree leaves; results of XRF analyses, autumn 2014 and 2015 (mg.kg^{-1}dry weight)*

		2014				
		% found sampling points	**Minimum**	**Maximum**	**Average**	**P-value**
Fe	**Site 1**	100.00	569.00	16,232.00	3,083.27	-
	Site 2	100.00	1,711.00	17,007.00	3,814.40	
Mn	**Site 1**	100.00	1,225.00	18,759.00	5,259.80	***
	Site 2	100.00	1,820.00	33,200.00	10,253.30	
Ni	**Site 1**	3.00	166.00	178.00	172.00	-
	Site 2	25.00	225.00	302.00	256.60	
Cu	**Site 1**	100.00	382.00	1,193.00	736.47	*
	Site 2	100.00	542.00	1,500.00	993.70	
Zn	**Site 1**	100.00	180.00	1,197.00	390.20	-
	Site 2	100.00	182.00	551.00	362.90	
Rb	**Site 1**	100.00	8.00	107.00	35.70	**
	Site 2	100.00	13.00	57.00	26.00	

		% found sampling points	Minimum	Maximum	Average	P-value
2014						
Sr	Site 1	100.00	53.00	604.00	196.07	**
	Site 2	100.00	84.00	242.00	146.40	
Zr	Site 1	13.00	13.00	21.00	17.00	-
	Site 2	5.00	18.00	18.00	18.00	
Mo	Site 1	43.00	3.00	10.00	4.78	-
	Site 2	50.00	4.00	13.00	6.50	
2015						
Mn	Site 1	57.00	2,400.00	40,800.00	7,864.71	-
	Site 2	50.00	2,800.00	22,300.00	8,720.00	
Fe	Site 1	60.00	1,282.00	6,800.00	2,656.67	-
	Site 2	45.00	1,144.00	26,800.00	4,524.78	
Zn	Site 1	50.00	220.00	3183.00	655.47	**
	Site 2	25.00	182.00	257.00	222.00	
Rb	Site 1	47.00	32.00	330.00	85.93	*
	Site 2	30.00	23.00	62.00	42.67	
Sr	Site 1	100.00	63.00	399.00	190.23	***
	Site 2	100.00	52.00	187.00	102.70	

*** $P < 0.001$, ** $P < 0.01$ **, *$P < 0.05$, – Wh no statistical significance

DISCUSSION

There is very little information about the metal content in forest species stands leaves. Having used the information available, it can be stated that elements concentration found in samples from the areas of interest, in terms of average parameters, exceed or match the values measured by other authors in localities loaded by increased depositions of elements found (Tab. II). Both in site 1 and site 2 localities there are Fe, Ni, Cu, Mo, Rb, Mn and Sr. Values in Tab. III are exceeded by Zn (site 1, site 2; according to Krpata *et al.* 2009) in maximum parameters (Tab. II). The statistically significant difference was recorded on the locality site 1 in terms of Rb, Sr in 2014 and Zn, Rb and Sr in 2015. There is no comparable available data on Zr content in leaves. We cannot say unambiguously that area with uninterrupted mining is more seriously polluted than area when mining had been finished.

Current forest at site 2 contains 58.40 % of *Picea abies* L., 24.87 % of Pinus sylvestris L. and 2.89 % of *Abies alba* Mill. (Uhúl 2016). Deciduous trees occur sporadically (personal observation). However, natural conditions do not support the proper growth of coniferous trees. Souček and Tesař (2008) say that according to the prevailing management set of stands (MSS is characterized by the identical functional focus, natural conditions and stand ratios; relevant details are specified in Decree no. 83/96 Coll.) at the research areas, representation of conifers should not exceed 20 %. Plíva (1987) also said that according to prevailing set of forest types (SFT depends on the ecological relationship and commercial significance of stands), deciduous trees should reach almost 100 %. It follows that the tree species composition of the forest environment in terms of areas of interest is focused on its commercial use: however, natural ecological forest functions are not considered at all. This situation becomes unsatisfactory in terms of forest impact on soil pH modification (i.e. immobilization metal pollution in ecosystem).

Deciduous trees, which are practically missing in the areas of interest, act on the metals immobilization in the environment in two ways: they modify pH and bind metals of an organic substance from litter. Spur and Barnes (1980) stated that deciduous species are able in one rotation exhaust from the subsoil 3 to 4 times more nutrients (basic cations) than coniferous species. Thus depleted nutrients are transmitted in the form of litter in the upper layers of soil: those are particularly elements such as Ca, Mg, K and partially Na. For some time, they are able to balance (neutralize) the higher sulphur content (from the atmosphere); in case of areas of interest also sulphur deposits from waste water from mining industry. Fagus sylvatica L. belongs to woody species characterized by high potential of positive pH soil modification. Kacálek *et al.* (2010) presented pH increase on 12-year beech stands by 0.90 pH units. Hruška and Cienciala (2002) presented the average pH increase for deciduous species comparing to coniferous by 0.70 and at maximum by 1.40 pH units. Further significant factor presented by Hruška and Cienciala (2002) are organic substances in the soil effecting heavy metals immobilization. Heavy metals are bound in organic compounds, which are inaccessible to the plants.

The possible direction for the management of areas contaminated by metals deposition may consist in rearrangement of forest stands and

II: *Concentrations of elements in tree dried leaves presented by other authors in contaminated sites and reference localities*

Element	Tree leaves	mg.kg^{-1}	Conc.	Author
Cu	*Platanus hispanica* Münchh.	38.96	-	Rodríguez-Germade *et al.* (2014)
	Juglans regia L.	0.34–13.80	UA	Dogan *et al.* (2014)
	Quercus pubescens Willd.	5.15–6.41	-	Bargagli *et al.* (2002)
		5.74	+	
	Fagus silvatica L.	11.00–13.20	-	Maňkovská *et al.* (2004)
Fe	*Fagus silvatica* L.	163.00–1046.00	-	Maňkovská *et al.* (2004)
	Malus domestica Borkh.	123.00	+	Barker a Pilbeam (2007)
	Prunus persica L.	66.00–124.00	+	
		44.00–58.00	-	
	Juglans regia L.	12.72–698.20	UA	Dogan *et al.* (2014)
	Quercus pubescens L.	112.50–1143.00	-	Bargagli *et al.* (2002)
		127.00	+	
Mo	*Citrus* L.	0.06	-	Zekri a Obreza (2015)
		0.06–0.09	-	
		0.10–1.00	+	
		2.00–50.00	-	
	Carya illinoinensis Wangenh.	>2.00	+	Heerema (2013)
Mn	*Fagus silvatica* L.	836.00–1774.00	-	Maňkovská *et al.* (2004)
		458.00	+	
Ni	*Tilia tomentosa* Moench	1.74–7.27	+	Stanković *et al.* (2011)
	Phyllanthus L.	1,090.00–60,170.00	Hpa.	Seregin a Kozhevnikova (2005)
	Juglans regia L.	0.13–2.744	UA	Dogan *et al.* (2014)
	Quercus pubescens L.	3.09–8.21	-	Bargagli *et al.* (2002)
		4.81	+	
Rb	*Fagus japonica* Maxim.	10.00	+	Yamagata *et al.* (1959)
	Quercus crispula Blume	2.00–5.00	+	
	Sorbus commixta Hedl.	4.00	+	
	Acer Tschonoskii Maxim.	6.00	+	
	Acer Mono Maxim.	4.00	+	
	Aesculus turbinata Blume	3.00	+	
	Tilia japonica Miq.	5.00	+	
Sr	*Betula* L.	15.10–53.90	+	Rodushkin *et al.* (2015)
	Acer pseudoplatanus L.	106.00	-	Simon *et al.* (2011)
		54.00	-/+	
		68.00	+	
	Citrus sinensis L.	>7,000.00	-	Wutscher (1999)
Zn	*Populus tremula* L.	486.00–974.00	-	Krpata *et al.* (2009)
		340.00	+	
	Fagus silvatica L.	53.50	-	Maňkovská *et al.* (2004)
		30.30–40.50	+	
	Citrus L.	2.00–50.00	-	Zekri a Obreza (2015)
	Carya illinoinensis Wangenh	>2.00	+	Heerema (2013)
	Prunus persica L.	17.90	-	Tezotto *et al.* (2013)
	Malus domestica Borkh.	12.50	-	
	Juglans regia L.	7.362–56.03	UA	Dogan *et al.* (2014)
	Quercus pubescens Willd.	15.00–22.70	-	Bargagli *et al.* (2002)
		20.40	+	

"UA" Urban Area; "Hpa" hyper accumulators; "+" reference sites, localities with no load or optimal concentrations; "-" localities affected by pollution, high values the appropriate desirable management. Having applied site 1 and site 2 areas of interest, we can introduce the basic framework and the benefits of an innovative approach to similarly loaded sites. The basic management stimulus should become a pH soil modification.

The MSS areas were identified in the site 2 locality area suitable for further rearrangement of the entire acreage of 610.69 ha. The active area of the total equals 481.76 ha; it is marked with contour lines from the east and west, with a road network from the north and with the stream Loučka from the south. The active area is understood as the area where the tree species composition is able to effect positively pollutants immobilization in the ecosystem, i.e., without terrain barrier, which can restrict circulation of nutrients in the ecosystem. By Kacálek *et al.* (2010), 12-year beech stand is able at the litter amount (Tab. III) as stated by Dietrich (1963) and Peřina (1960), on the area of 481.76 ha introduce in the environment 8,749.00–18,846.41 kg.ha^{-1} Ca and 1,218.71–2,625.44 kg.ha^{-1} Mg. The ration between a spruce monoculture and beech forest is in favour of beech forest in Ca production of 2.13–4.58 : 1 and in Mg production of 2.07–4.46 : 1.

On the site 1 locality it is useful to use the land, which serves currently as production meadows, and convert them to forest land. The total acreage of selected area is 157.89 ha.These newly selected areas in the site 1 locality are situated between the rail and road causeway (they make a hydro-geological barrier), i.e. in the area with no affect of current forest canopy vegetation. 12-year beech stand (by Ca and Mg content as stated by Kacálek *et al.* (2010) and at litter amount as stated by Dietrich (1963) and Peřina (1960) is able to subsidy the ecosystem of an area of 157.89 ha with 2,867.38–6,177.15 kg Ca and 399.42–860.46 kg Mg annually. The Ca (mg.kg^{-1}) litter beech/spruce ratio is 2.13–4.58 : 1 for Mg, then 2.07–4.46 : 1 (calculated by Kacálek *et al.* 2010).

Logging can withdraw high amount of basic cations from the area (Hruška 2009); this fact contributes to acidification of soil, water in watercourses and its sediments (Hruška *et al.* 2006). However, as stated by Hruška and Cienciala (2002), the loss of Ca and Mg can be reduced by 40 % if branches are kept in the logging site. Klimo *et al.* (2001) stated that while keeping branches and bark in the logging site, Ca loss can be reduced by 23 % and Mg loss by 19 %. The most appropriate method for newly established stand might consist in applying the selective logging, or these stands could belong to areas with limited or fully prohibited commercial logging.

The change of tree species composition can be an appropriate alternative to liming forests. Liming and further support of microbial activity may result in N and K deficiency in the soil (Ouimet and Moore 2015). Liming is able to increase soil pH. It is a comparatively short effect, however, as stated by Deromea and Saarsalmi (1999), 5 years after application of various fertilizers with various dolomite content, at the dosage of 2,000 kg.ha^{-1} (Ca 420, 98 and 315 kg.ha^{-1} and 100.61 and 50 kg. ha^{-1} Mg), the pH value was almost at the same level as before liming. Deromea and Saarsalmi (1999) reported a reduction of Zn, Ni and Cu; regardless the fact, the graphs presented in the results show that locality, which is the most seriously exposed to the pollution from the metallurgical industry, offers the trend to the increased concentration of Zn, Ni and Cu in the soil.

The dose of Ca 420.98 kg.ha^{-1} (Deromea and Saarsalmi 1999) applied through liming can be reached by beech litter subsidy in 12-year beech canopy stand in 11–23 years; the dose of 315 kg.ha^{-1} in 8–17 years, the dose of 98 kg.ha^{-1} in 3–5 years. The Mg subsidy from the litter is lengthier than in case of Ca. The dose of 61 kg.ha^{-1} Mg as stated by (Deromea and Saarsalmi 1999), can be reached in 11–24 years and the dose of 50 kg.ha^{-1} in 9–19 years (calculated by Kacálek *et al.* 2010; Dietrich 1963; Peřina 1960). The change of tree species composition comparing to liming, has the advantage of long-term effect: in addition, liming has to be repeated regularly so that the effect of desired metals immobilization and pH increase could be maintained. In terms of long-term effect, this fact may become a financial burden for the forest land owners.

III: *Litter amount and its element composition (Ca, Mg) on areas with Picea abies L. and Fagus silvatica L. stands*

Tree species	Litter (kg.ha^{-1})[a]	Elements content in litter (mg.kg^{-1})[b]		Elements from litter to soil (kg.ha^{-1})*	
		Ca	Mg	Ca	Mg
Fagus silvatica	3,662.00–7,889.00	4,959.20	690.80	18.16–39.12	2.53–5.45
Picea abies	3,214.00	2,656.60	380.40	8.54	1.22

[a]Dietrich (1963) and Peřina (1960), [b]Kacálek *et al.* (2010), * calculated by Dietrich (1963) and Peřina (1960) and Kacálek *et al.* (2010)

CONCLUSION

The areas of interest show a significant redistribution of metals in woody species leaves. The analyses showed increased concentrations of Cu, Fe, Mn, Mo, Ni, Rb, Sr, Zn and U comparing to other authors who had been conducting research on areas exposed to metal pollution. The statistically significant difference between the metal content between the upper, middle and lower stream segments was not demonstrated on either of sites in question. Alluvial forest ecosystems, being recipients of mining waste from Dolní Rožínka and Olší, are heavily affected; unfortunately, there is no trend to improve the situation in terms of the distance from the source of pollution. Both site 1 and 2 are seriously metal polluted; therefore management of active mining areas is as important as monitoring after finished mining activities. The measures proposed to model examples are based on the principle of converting the stand composition from the dominated *Picea abies* L. to deciduous forests with prevailing *Fagus silvatica* L. The proposed forest stand management for the localities affected by deep metal mining also pursue the elimination of basic cations loss due to logging. These procedures, although it is a long-term process, are a convenient alternative to forest liming.

Acknowledgement

This research was supported by the Ministry of Education, Youth and Sports of the Czech Republic under the project CEITEC 2020 (LQ1601).

REFERENCES

BARGAGLI, A., MONACI F. and AGNORELLI C. 2003. Oak leaves as accumulators of airborne elements in an area with geochemical and geothermal anomalies. *Environmental Pollution*, 124: 321–329.

BARKER, A. V. and PILBEAM, D. J. 2007. *Handbook of plant nutrition*. New York: Taylor and Francis. 773.

CÍMALA, Z. 1997. *Po stopách průzkumu a těžby uranových ložisek na Moravě a Východních Čechách*. Dolní Rožínka, o.z. GEAM. 130.

CROMPTON, T. R. 1996. *Analysis of Solids in Natural Waters*. Berlin: Springer. 271.

DEROME, J. and SAARSALMI A. 1999. The effect of liming and correction fertilisation on heavy metal and macronutrient concentrations in soil solution in heavy-metal polluted scots pine stands. *Environmental Pollution*, 104: 249–259.

DIETRICH, H. 1963. Untersuchungen zum Nährstoffkreislauf von Fichtenbeständen im Osterzgebirge. *Archiv für Forstwesen*, 12: 1116 – 1136.

DOGAN Y., UNVER M. C., UGULU I., CALIS M. and DURKAN N. 2014. Heavy metal accumulation in the bark and leaves of Juglans regia planted in Artvin City, Turkey. *Biotechnol Biotechnol Equipment*, 28: 643–649.

HÁJEK, A. and KOSCIELNIAK P. 1997. *Hydrology and hydrogeology in Valley Stream Hadůvka after flooding bearing Olší - evaluation of water sources and water chemistry of the stream Hadůvka*. [in Czech: *Hydrologie a hydrogeologie v údolí potoka Hadůvka po zatopení ložiska Olší - zhodnocení pramenů a chemismu vod v potoce Hadůvka*]. Dolní Rožínka, o. z. GEAM. 38.

HARTER, R. D. 1983. Effect of soil pH on adsorption of lead, copper, zinc, and nickel. *Soil Science Society of America Journal*, 47: 47–51.

HEEREMA, R. 2013. *Diagnosing Nutrient Disorders of New Mexico Pecan Trees*. Las Cruces: New Mexico State University.

HRUŠKA, J. and CIENCIALA E. 2002. *Dlouhodobá acidifikace a nutriční degradace lesních půd – limitující faktor současného lesnictví*. Praha: Ministerstvo životního prostředí.

HRUŠKA, J., OUHELE F., KRÁM P. and SKOŘEPOVÁ I. 2009. Účinky kyselého deště na lesní a vodní ekosystémy. Vliv depozic síry a dusíku na půdy a lesy. *Živa*, 3: 141–144.

HRUŠKA, J., MAJER V. and FOTTOVÁ D. 2006. Vliv kyselé depozice na chemismus povrchových vod v Krkonoších. *Opera Corcontica*, 43: 95–110.

INTERNATIONAL ATOMIC ENERGY AGENCY., 1997. *Sampling, storage andsample preparation procedures for X ray fluorescence analysis of environmental materials*. Viena: IAEA.

IANCULESCU, M., IONESCU M., LUCACI D., NEAGU S. and MÃCÃRESCU C. 2009. Dynamic of pollutants concentration in forest stands from Copsa Mica industrial area. *Annals of Forest Research*, 52: 207–226.

KACÍLEK D., NOVÁK J., BARTOŠ J., SLODIČÁK M., BALCAR V. and ČERNOHOUŠ V. 2010. Forest-floor humus and topsoil properties related to forest-tree species. *Zprávy lesnického výzkumu*, 55: 19–25.

KLIMO, E., BEDNÁŘOVÁ, E., HADAŠ, P., KLIMO, E., MARKOVÁ, I., MENŠÍK, L., PURCHART, L., REMEŠ, M., SUCHOMEL, J., TRUPAROVÁ, S., DRÁPELOVÁ, I., LORENCOVÁ, H., LOMSKÝ, B., ŠRÁMEK, V. and MERKLOVÁ L. 2001. *Lesnická ekologie*. Brno: Mendel University in Brno. 115.

KRPATA, D., FITZ W., PEINTNER, U., LANGER, I. and SCHWEIGER, P. 2009. Bioconcentration of zinc and cadmium in ectomycorrhizal fungi and associated aspen trees as affected by level of pollution. *Environmental Pollution*, 157: 280–286.

LUKE C. L. 1968. Determination of trace elements in inorganic and organic materials by x-ray fluorescence spectroscopy. *Analytica Chimica Acta*, 41: 237–250.

LUSK, K. and HÁJEK A. 2003. *Analýza zaplavování uranových dolů v České republice*. [Online]. Available at: http://slon.diamo.cz/hpvt/2003/sekce_z/PZ15%20P.htm. [accessed Apr 18, 2016].

MAŇKOVSKÁ, B., GODZIKB, B., BADEAC, O., SHPARYKD, Y. and MORAVČÍKE, P. 2004. Chemical and morphological characteristics of key tree species of the Carpathian Mountains. *Environmental Pollution*, 130: 41–54.

OUIMET, R., MOORE, J. D. 2015. Effects of fertilization and liming on tree growth, vitality and nutrient status in boreal balsam fir stands. *Forest Ecology and Management*, 345: 39–49.

PETŘINA, V. 1960. *Přeměna borových monokultur na plistocenních terasách*. Praha: Státní zemědělské nakladatelství. 210.

PLÍVA, K. 1987. *Typologický klasifikační systém ÚHÚL*. Brandýs nad Labem: ÚHÚL. 52.

POUZAR, M., ČERNOHORSKÝ T. and SÁKRA T. 2006. ED XRF Spectrometric Determination of Total Sulfur Content in Leaves, *Chemia Analityczna (Warsaw)*, 51: 173–178.

RODRÍGUEZ-GERMADE, I., MOHAMED, K. J., REY, D., RUBIO, B. and GARCÍA, Á. 2014. The influence of weather and climate on the reliability of magnetic properties of tree leaves as proxies for air pollution monitoring. *Science of the Total Environment*, 468–469.

RODUSHKIN, I., PALLAVICINI N., ENGSTRÖM E., SÖRLIN D., ÖHLANDER B., INGRIA J. and BAXTERB D. 2015. Electronic Supplementary Information for Assessment of natural variability of B, Cd, Cu, Fe, Pb, Sr, Tl and Zn concentrations and isotopic compositions in leaves, needles and mushrooms using single sample digestion and two-column matrix separation. *Journal of Analytical Atomic Spectrometry*, 1–4.

SALMINEN, R., BATISTA, M. J., BIDOVEC, M., DEMETRIADES, A., DE VIVO, B., DE VOS, W., DURIS, M., GILUCIS, A., GREGORAUSKIENE, V., HALAMIC, J., HEITZMANN, P., LIMA, A., JORDAN, G., KLAVER, G., KLEIN, P., LIS, J., LOCUTURA, J., MARSINA, K., MAZREKU, A., O'CONNOR, P. J., OLSSON, S.Å., OTTESEN, R.-T., PETERSELL, V., PLANT, J.A., REEDER, S., SALPETEUR, I., SANDSTRÖM, H., SIEWERS, U., STEENFELT, A. and TARVAINEN, T. 2005. *Geochemical atlas of Europe. Part 1, Background information, methodology and maps*. Espoo: Geological Survey of Finland. 526.

SANDIFER R. D. and HOPKIN S. P. 1996. Effects of pH on the toxicity of cadmium, copper, lead and zinc to Folsomia candida Willem 1902 (Collembola) in a standard test system. *Chemosphere*, 33: 2475–2486.

SEDLÁČEK, B. 2007. *50 years of mining activities on the deposit* [in Czech: *Uplynulých 50 let dobývání na ložisku*]. Stráž pod Ralskem: Dolní Diamo s.p.

SEREGIN, V. and KOZHEVNIKOVA, A. D. 2006. Physiological role of nickel and its toxic effects on higher plants. *Russian Journal of Plant Physiology*, 53: 257–277.

SIMON, E., BRAUN, M., VIDIC, A., BOGYÓ, D., FÁBIÁN, I. and TÓTHMÉRÉSZ, B. 2011. Air pollution assessment based on elemental concentration of leaves tissue and foliage dust along an urbanization gradient in Vienna. *Environmental Pollution*, 159: 1229–1233.

SOUČEK, J. and TESAŘ, V. 2008. Metodika přestavby smrkových monokultur na stanovištích přirozených smíšených porostů. Recenzovaná metodika. *Lesnický průvodce*, 4: 37.

SPUR, S. H. and BARNES, B. V. 1980. *Forest Ecology*. 3rd edition. London: John Wiley and Sons. 87–93.

STANKOVIĆ, D., KNEŽEVIĆ, M., KRSTIĆ, B., ŠIJAČIĆ-NIKOLIĆ M. and VILOTIĆ D. 2011. Nickel content in plants and soil in the area of the protected natural resource „Avala" - Belgrade. *Bulletin of the Faculty of Forestry*, 103: 131–146.

ŠENK B. 2001. *Likvidace U-rud Olší okres Žďár nad Sázavou*. [Online]. Available at http://slon.diamo.cz/hpvt/2001/sekce/sanace/11/S11.htm. [accessed Apr 22, 2016].

TEZOTTO, T., FAVARIN, J.L., NETO, A.P., GRATÃO, P.L., ANTUNES ZEVEDO, R. and MAZZAFERA, P. 2013. Simple procedure for nutrient analysis of coffee plant with energy dispersive X-ray fluorescence spectrometry (EDXRF). *Scientia Agricol*, 70: 263–267.

TOLASZ, R. 2007. *Climate Atlas Of Czechia* [in Czech: *Atlas podnebí Česka*]. Praha: Český hydrometeorologický ústav. 255.

TYLER, G. and OLSSON, T. 2006. The importance of atmospheric deposition. charge and atomic massto the dynamics of minor and rare elements in developing. Ageing and wilted leaves of beech (Fagus sylvatica L.). *Chemosphere*, 65: 250–260.

ÚHÚL 2016. *Datový sklad, Lesní hospodářské osnovy*. [Online]. Available at http://eagri.cz/public/app/uhul/ds_lho/ [accessed Apr 18, 2016].

USNESENÍ VLÁDY ZE DNE: 23. KVĚTNA 2007 Č. 565 k prodloužení těžby uranu na ložisku Rožná v lokalitě Dolní Rožínka

VÁŠA, J., TOMAN, Z., ŠPATKA, R., CHOCHOLÁČ, J. and TOMANOVÁ, L. 2015. *Zpráva o výsledcích monitoringu a stavu složek životního prostředí o. z.* GEAM za rok 2014. Stráž pod Ralskem: DIAMO, s. p.

VESELÝ, M. 2006. *Provozně manipulační řád: Odkaliště KI*. Stráž pod Ralskem: DIAMO, s. p.

VIOLANTE, A., COZZOLINO, V., PERELOMOV, L., CAPORALE, A.G. and PIGNA, M. 2010. Mobility and bioavailability of heavy metals and metalloid in soil environments. *Journal of soil science and plant nutrition*, 10: 268 – 292.

VYHLÁŠKA MINISTERSTVA ZEMĚDĚLSTVÍ ZE DNE 18. BŘEZNA 1996 o zpracování oblastních plánů rozvoje lesů a o vymezení hospodářských souborů

WMS map server 2016. Geologická mapa 1:50000. [Online]. Available at http://mapy.geology.cz/arcgis/services/Geologie/geocr50/MapServer/WmsServer? [accessed Apr 14, 2016].

WUTSCHER, H. K. 1999. Geographic variation of strontium concentrations in orange leaves. *Communications in Soil Science and Plant Analysis*, 30: 9–10.

YAGI, S., ABD RAHMAN A. E., ELHASSAN1 G. O. M. and MOHAMMED A. M. A. 2013. Elemental Analysis of Ten Sudanese Medicinal Plants Using X-ray Fluorescence. *Journal of Applied and Industrial Sciences*, 1:49–53.

YAMAGATA, N., YAMAGATA, T. and MATSUDA S. 1959. The different distribution of rubidium and cesium in Natural Plants. *Bulletin of the Chemical Society of Japan*, 32: 407–414.

ZEKRI, M. and OBREZA, T. 2015. *Molybdenum (Mo) and Nickel (Ni) for Citrus Trees*. [Online]. Available at https://edis.ifas.ufl.edu/pdffiles/SS/SS61800.pdf [Accessed: 2016, April 14].

ZENG, J., ZHANG, G., BAO, L., LONG, S., TAN, M., LI, Y., MA, CH. and ZHA, Y. 2013. Sulfur speciation and bioaccumulation in camphor tree leaves as atmospheric sulphur indicator analyzed by synchrotron radiation XRF and XANES. *Journal of Environmental Sciences*, 25:605–612.

ZUUR, A., IENO, E. N., WALKER, N., SAVELIEV, A. A. and SMITH, G. M. 2009. *Mixed Effects Models and Extensions in Ecology with R*. Berlin: Springer. 574.

Contact information

Ing. David Juřička: djuricka@seznam.cz
Ing. Libor Mikl: Libor.Mikl@seznam.cz
Ing. Marcela Muchová: xmuchov3@node.mendelu.cz
Ing. Jan Hladký, Ph.D.: pudoznalec@gmail.com
RNDr. Jitka Novotná: xnovot@mendelu.cz
Mgr. Bc. Radka Frýzová: radka.fryzova@mendelu.cz
Ing. Martin Brtnický: martin.brtnicky@seznam.cz
doc. Mgr. Jindřich Kynický, Ph.D.: jindrak@email.cz