Oecologia Montana 2019, **28,** 70-76

Mercury as a risk factor for woody plants in the locations of Veľký Choč and Čierny Váh

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Abstract. In our work we studied samples of *Abies alba* Mill., *Picea abies* Karst., and forest soils. These species are significant as a bio indicator of pollution. Samples were collected from two locations: Veľký Choč and Čierny Váh. At each locality we selected twelve field sites, from which we collected samples of needles at the end of the growing season. They were analyzed with the Advanced Mercury Analyzer AMA 254 (single-purpose absorption spectrophotometry). Soil samples taken from both localities had mercury concentration values ranging from 0.1474 to 0.15224 mg.kg^{-1}. Concentration in assimilation organs had mercury concentration values ranging from 0.00635 to 0.15224 mg.kg^{-1}. The highest value was measured in three year old needles from Veľký Choč – 0.15224 mg.kg^{-1}. We can confirm that the observed areas are not contaminated by mercury.

Key words: Abies alba, Picea abies, assimilation organs, forest soil

Introduction

Mercury (Hg) is a serious pollutant of all environmental components including the food chain, and its effects are often negative. Originally, mercury contamination was considered an urgent issue local to Slovakia, but it has grown into a worldwide chronic problem. It is one the oldest known metals, and gets into the environment mainly through volcanic activity and the burning of coal. This toxic element is used in industrial applications, agriculture, and medicine. An important geochemical barrier to mercury is the soil in which Hg is suspended, preventing it from contaminating organic matter and other soil components. Under certain conditions, mercury may be re-mobilized and transferred to organisms or other environmental components.

Mercury enters the soil as a result of anthropogenic activities such as mining, fossil fuel combustion, application of agrochemicals (pesticides, fertilizers), liming, sewage sludge and household and industrial waste. Heavy metals are also released the the parent rock in the process of pedogenesis (Naidu *et al.* 1996). The soil under trees contains two to three times more mercury than areas without tree vegetation (Kolka *et al.* 1999). Soils with increased humus contain higher concentrations of Hg. Methyl mercury in soil sediments does not exceed 1.5% of the total mercury content (Cornelis *et al.* 2005).

Soil mercury pollution is affected by several factors including soil moisture, sunlight and temperature (Frescholtz and Gustin 2004; Gustin *et al.* 2004; Gustin and Stamenkovic 2005). The speed of this process depends on the soil composition, the amount of clay minerals, organic matter, pH and redox potential. The mercury content increases in surface horizons. Its volatility increases with alkalinity of the environment and with increasing temperature (Gábriš 1998; Zaujec 1999). According to Vojtáš (2000), mercury accumulates mainly in humus horizons due to its volatility. Mercury in plants is considered to be one of the most toxic elements. It affects their physiological and biochemical reactions with high affinity for SH - groups of amino acids. Plants take up both organic and inorganic forms of Hg through their root system. The roots often contain high concentrations of mercury - up to 95%, but rarely, mercury can be transferred into the stem, where concentrations are less than 5% (Millhollen *et al.* 2006).

The penetration of toxic substances is influenced by several soil factors such as soil pH, soil types, humidity, soil accessibility, temperature, soil humus content, heavy metal concentration and form, oxidation-reduction conditions around the root system and the use of fertilizers and plant protection products. Factors influencing the content of absorbed metal by a plant are the movement of metal from the soil to the surface of the root system, contamination and the form of metal in the soil solution, transport of the metal from the surface parts to the inner parts of the roots and translocation of the metal from the root to shoots (Broadley *et al.* 2007).

Leaves are covered with a thin layer of lipids called cuticula. Its role is to protect the leaf from pollutants and water loss. Concentrations of mercury in leaves correlate positively with leaf age. Leaves accumulate the most mercury during the growing season. The assimilation organs absorb atmospheric Hg through the vents, where they are subsequently converted to Hg_2 (Rea *et al.* 2002). Concentrations of Hg from the leaves and trunk may be washed away by precipitation or may gradually fade from the leaves, as this metal is characterized by a high evaporation rate (Munthe *et al.* 1995; Schwesig and Matzner 2001; St. Louis *et al.* 2001). The bark and leaves turn out to be the largest assimilates of Hg from the atmosphere. Air deposition is responsible for up to 90% of Hg uptake in plants. Tree bark only absorbs 10% of mercury. Mercury affects the photosynthesis in both light and dark phases. Intensity is inhibited by more organic compounds than inorganic compounds (Hronec 1996). The highest concentrations were recorded during high photosynthetic activity. The rate of intake of Hg decreases toward the end of the growing season. Absorption of Hg is influenced by wind speed, morphology (hair, wax) and leaf texture (Lindberg and Stratton 1998; Rea *et al.* 2002). Mercury is not only attached to the leaf surface, but also penetrates the epidermis and plant tissues. It enters the leaves primarily through trichomes, cuticles and dental openings as Hg^0. Plants not only sustain mercury content in their leaves, but also excrete it in gaseous form. This leaf absorption of mercury has been proven in the following plant species: *Acer rubrum*, *Picea abies* and *Liriodendron tulipifera* (Hanson *et al.* 1995). By the end of autumn, deciduous trees can contain up to ten times more mercury (Rea *et al.* 2002). High concentrations of Hg result in complete arrest of the assimilation organ growth (Ericksen *et al.* 2003).

Each type of vegetation represents several aspects of the mercury cycle in forest soils. The overlying organic horizon under coniferous trees accumulates up to 28% more Hg than the organic horizon under deciduous species. In general, conifers are more sensitive to contamination, due to their longevity. Organic material under coniferous vegetation absorbs less UV radiation, and potentially reduces photoreduction and evaporation of Hg (Carpi and Lindberg 1997). The soil under conifers on the south side of the slope accumulates more Hg than the stand exposed on the north side. *Abies balsamea* and *Fagus grandifolia* accumulate more Hg than *Acer* sp., *Larix dexidua* and *Betula* sp. Coniferous tree are excellent bioindicators of environmental pollution, detecting mercury, sulfur, chlorine, fluorine and heavy metal thresholds (Arndt *et al.* 1987). They are characterized by the long life of their needles. Excessive Hg values also cause an increase in mitochondria and endoplasmic reticulum. The limiting ability of photosynthetic CO_2 fixation enzymes has also been demonstrated (Hronec 1996). According to Bielek (2000), mercury intake by plants can be reduced by liming soils or through the use of phosphates, although there are contradictory opinions in this respect.

Mercury binds in RNA, DNA and several types of synthetic polyribosomes. For eukaryotic cells, the organic forms of mercury are toxic CH_3HgCl, C_2H_5HgCl and $Hg(CH_3)_2$ (Liu *et al.* 1992). According to Maňkovská (1996a), Hg $(OH)^2$ and HgOHCl represent the greatest toxicity to plants. Cytoplasm acts as a defence mechanism against toxicity in plants, and has the ability to isolate toxic ions from complexes. The most dominant molecules include glutathione (GSH) and phytochelatin (PCs), which can isolate metal ions from the cytoplasm and subsequently facilitate their transport to the vacuoles. Amino acids (hystidine) and organic acids (citrate) are a natural component of the cytoplasm and act on metal complexes that reduce the toxicity of Hg in plants (McGrath and Zhao 2003).

Mining of mercury was a major industry during the First Czechoslovakian Republic, with maximum production reaching 100 tonnes in 1938. They mined mercury largely from metacinabarite and cinabarite, but also as a by-product from other mining processes and the processing of mineral raw materials. The most famous mercury mineral deposits are Malachov near Banská Bystrica, Merník north of Vranov, Rudňany, the Holy Trinity near Nižná Slana and Zenderling near Gelnica (Zorkovský 1972). River sediments indicate a high mercury content from the Spišsko - gemerské Rudohorie and the surroundings of Banská Bystrica (Maňkovská 1996b; Bodiš and Rapant 1999). Mercury is most often bound to sulfur and appears as complex or simple sulphides. The occurrence of mercury coincides with the mineralization of other metal chalkophilic elements. Mineralization took place in metallogenic regions. Most of the mercury was bound in older formations of siderosulfide phases and sulfide tetraedrites of hydrothermal mineralization in Spišsko - gemerskom Rudohorí. Long-term monitoring of heavy metals shows an improvement in the agricultural production situation.

Concentrations of mercury increase in grain and permanent grassland. In Slovakia, the most contaminated regions are Spišské Nová Ves and Gelnica. This monitoring also points to a gradual decrease in the concentration of mercury in fish and game. In Slovakia, mercury emissions have continued to decrease since 1990, with a reduction of 66.4% in emissions between 2001 and 2014 (Sedlák and Poráčová 2015). The aim of this study is to determine concentrations of mercury in assimilation organs of the tree species *Abies alba,* Mill and *Picea abies,* Karst and in soil near Veľký Choč and Čierny Váh, as well as to perform statistical analysis and evaluation of this data.

Matherial and Methods

Sample assimilation organs (*Abies alba, Picea abies*) and soil were collected from two different remote locations. The first location was the hill of Veľký Choč located at an altitude of 1611 m (GPS coordinates for *Abies alba*: 1. sampling site: E: 19° 20´ 54.08", N: 49° 6´ 27.58"; 2. sampling site: E: 19° 20´ 32.01", N: 49° 6´ 40.16"; 3. sampling site: E: 19° 20´ 43.88", N: 49° 6´ 55.84"; GPS coordinates for *Picea abies*: 1. sampling site: E: 19° 20´ 52.86", N: 49° 6´ 29.07"; 2. sampling site: E: 19° 20´ 28.54", N: 49° 6´ 36.12"; 3. sampling site: E: 19° 20´ 42.52", N: 49° 6´ 54.32"). The second location was Čierny Váh, which has an alititude of 1160 m (GPS coordinates for *Abies alba*: 1. sampling site: E: 19° 52´ 22.73", N: 49° 1´ 28.00"; 2. sampling site: E: 19° 53´ 19.02", N: 49° 1´ 43.08"; 3. sampling site: E: 19° 53´ 58.26", N: 49° 1´ 24.08"; GPS coordinates for *Picea abies*: 1. sampling site: E: 19° 52´ 5.60", N: 49° 1´ 13.44"; 2. sampling site: E: 19° 53´ 15.97", N: 49° 1´ 37.24"; 3. sampling site: E: 19° 53´ 51.69", N: 49° 1´ 33.86". Choč is a dominat peak within the Choč mountains, extending on the northern side of Slovakia, near Ružomberok, Dolný Kubín and Liptovský Mikuláš. Based on its geomorphology, Slovakia belongs to the Alps – Himalayan system and the Carpathians subsystem. West Carpathian province, and Inner West Carpathians subprovince, Fatra – Tatra area, wholes Choč mountains, subassembly Choč, Sielnické vrchy and Prosečné, western part extends into whole Great Fatra, subassembly Šípska Fatra (Mazúr and Lukniš 1978). This area is characterized by a moderate climate, with harsher temperatures found at higher elevations. The average annual temperature is between 4-6° C. Precipitation averages 800-1000 mm per year. July is the hottest month of the year, with average temperatures between 12-16° C. There are 100-150 days of snow cover on average. Soil is comprised dominantly of redzina and cambisol types, and clay, stony soils are the dominant class.

Čierny Váh located in the Turkova nature reserve, which is a significant forested area. Čierny Váh extends on the northen edge of Kráľovohoľských Tatier, which is a part of the Low Tatras National Park protected zone (Majerová 2008). Čierny Váh extends through northen Slovakia, within the Liptovský Mikuláš region. Within Geomorphology, the territory of Slovakia belongs to the Alpine-Himalayan system, Carpathians subsystem, West Carpathian province, Inner West Carpathians subprovince, Fatra – Tatra area, Low Tatras, subassembly Kráľovohoľské Tatry (Mazúr and Lukniš, 1978). Climate conditions in this region depend on the relief and the increasing altitude. This area has a colder climate with more precipitation, averaging 1600 mm. The average annual temperature is between 2-4° C. July is the warmest month of the year. In January, the average temperature is -9° C. There are 130 days of snow cover, on average. Dominant soil types include podzols, rankre, litozeme and cambisol. Loamy sand soils, stony and clay sandy soils are the dominant soil classes (Majerová 2008).

We chose 12 sample locations, from which we collected needle samples at the end of the growing season (September 2018). At each site we collected one twig, which was subsequently divided into one, two, and three year-old needles. The collected samples were placed in polythene bags and transported to the laboratory. Samples were dried at laboratory temperature. Dried *Picea abies* and *Abies alba* needles were homogenized to a fine powder in a FAGOR. Each sample was ground for approximately 3-5 minutes at a frequency of 50 Hz. Samples were measured by an Advanced Mercury Analyser (AMA 254). Soil was dried at laboratory temperature. Dried soil was sifted and samples were measured with the AMA 254. Samples (40-60 mg) were placed into the dosing boat. The first stage of analysis is known as the decomposition phase. During this phase, a sample container with a nominal amount of the matrix is placed inside a pre-packed combustion tube. This combustion tube-heated to ~750° C through an external coil-provides the necessary thermal decomposition of the sample into a gaseous form. The evolved gases are then transported (via an oxygen carrier gas) to the other side of the combustion tube. This portion of the tube, pre-packed with specific catalytic compounds, represents the area in the instrument where all interfering impurities (i.e. ash, moisture, halogens, and minerals) are removed from the evolved gases. Following decomposition, the cleaned, evolved gas is transported to the amalgamator for the collection phase. The amalgamator, a small glass tube containing gold-plated ceramics, collects all of the mercury in the vapor. With a strong affinity for mercury and a significantly lower temperature than the decomposition phase, the amalgamator is capable of trapping all mercury for subsequent detection. When all mercury has ben collected from the evolved gases, the amalgamator is heated to ~900° C essentially releasing all mercury vapor to the detection system. The released mercury vapor is moved through to the final phase of analysis-the detection phase. During the detection phase, all vapor passes through two sections of an apparatus known as a cuvette. The cuvette is positioned in the path length of a standard Atomic Absorption Spectrometer. This Spectrometer uses an element-specific lamp that emits light at a wavelength of 253.7 nm, and a silicon UV diode detector for mercury quantitation.

Data was processed using the STATISTICA 7 statistical program. Element measurements were analysed using analysis of variaton and Duncan´ s test, which determined concentrations of mercury for different ageed needles, locations, and species.

Results

The concentration of mercury in assimilation organs Abies alba

The highest value of the soil sample was measured in *Abies alba* in the locality Veľký Choč at the 3rd sampling site at altitude (818 m a.s.l.) of 0.2309 mg.kg^{-1} (Fig. 1). Measured values in *Abies alba* at locality Veľký Choč increase with altitude while values in the locality of Čierny Váh decrease.

According in the Fig. 2 in the locality Veľký Choč, mercury values are decreasing. Two year old needles had the highest mercury concentrations at 0.02714 mg.kg^{-1} between 3 sampling site at an altitude of 818 m a.s.l.

Mercury levels in samples taken from Čierny Váh are highest in 3 year old needles, and lowest in 1 year old needles. The lowest mercury values were 0.00646 mg.kg^{-1}, found in 1 year old needles (Fig. 3) from the 2nd sampling site, with an altitude of 905 m a.s.l. Concetration of mercury in the needles of *Abies alba* was higher at the locality of Veľký Choč than at Čierny Váh, which may be as a result of industry (particularly Mondi SCP operations), highway construction, heavy traffic and long – distance emissions. The assimilation organs of *Abies alba* accumulate less mercury than *Picea abies* needles. Overall, avarege mercury values show that spruce needles accumulate more mercury. According to these localities, the mercury content is higher in the abies in the Veľký Choč than in the spruce in the Čierny Váh

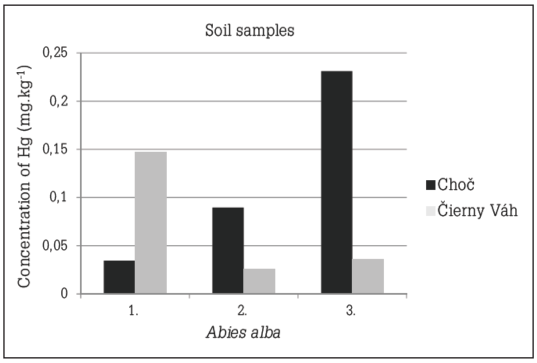

Fig. 1. The concentration of Hg in soil samples near *A. alba* on the investigated sites.

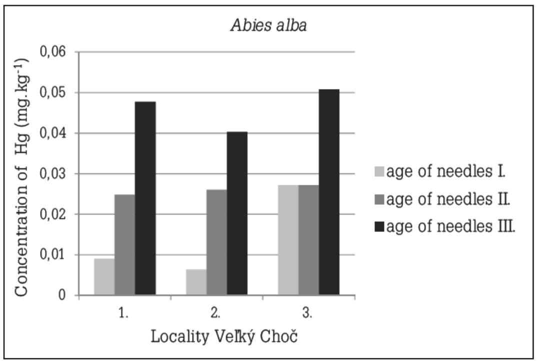

Fig. 2. Concentration of Hg in assimilation organs of the *Abies alba* at locality Veľký Choč.

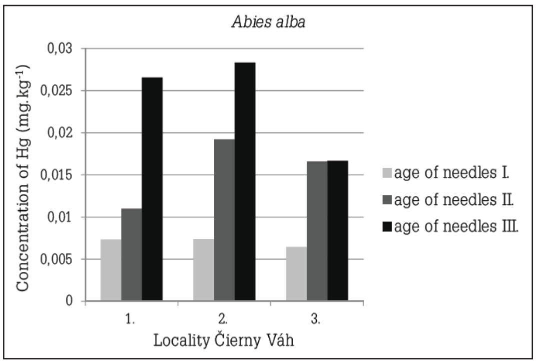

Fig. 3. Concentration of Hg in assimilation organs of the *Abies alba* at locality Čierny Váh.

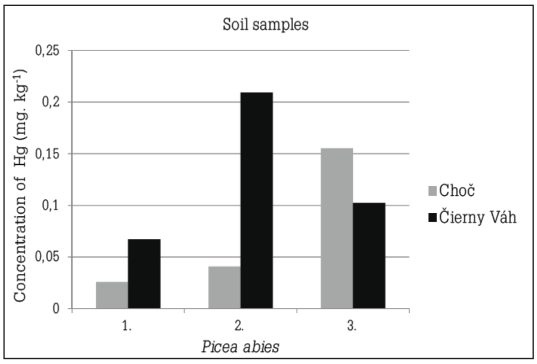

Fig. 4. The concentration of Hg in soil samples near *P. abies* on the investigated sites.

Fig. 5. Concentration of Hg in assimilation organs of the *Picea abies* at locality Veľký Choč.

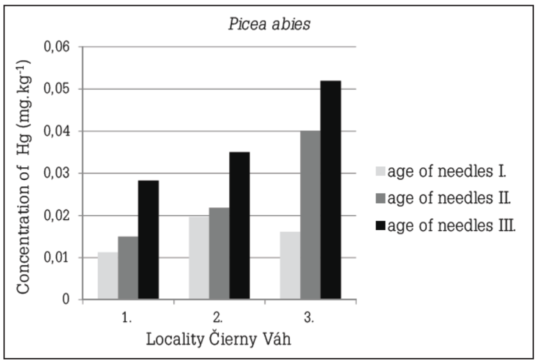

Fig. 7. Concentration of Hg in assimilation organs of the *Picea abies* at locality Čierny Váh.

The concentration of mercury in assimilation organs Picea abies

At the first sampling site, located at an altitude of 751 m a.s.l. in the locality of Čierny Váh, we measured the lowest mercury values of the soil samples (0.06701 mg.kg^{-1}) (Fig. 4).

As per Fig. 5, in the locality of Veľký Choč, mercury values are decreasing. Needles at 3 years of age have the most mercury at 0.01182 mg.kg^{-1}, then 2 year old needles, followed by 1 year old needles with the lowest concentration, measured at 0.01678 mg.kg^{-1}.

Fig. 6 shows the lowest mercury values were measured at Čierny Váh, with a concentration of 0.01122 mg.kg^{-1} for the 1 year old needles, at the 1st sampling site with an altitude of 751 m a.s.l. The highest mercury values were measured in 3 year old needles, at 0.05193 mg.kg^{-1} 3 at an altitude of 1039 m a.s.l.

Statistical processing

Based on the variant analysis, the differences in mean mercury concentrations between *Picea abies* and *Abies alba* are statistically significant. The average value of mercury in spruce needles (0.03085 mg.kg^{-1}) is higher than in *Abies alba* needles (0.02134 mg.kg-1) (Fig. 7).

There is a statistically significant difference in mercury concentration between the locality near Veľký Choč 2. (2nd sampling point) and other locations. The highest average value of mercury was at the 2nd sampling site in Veľký Choč at an altitude of 704 m a.s.l. - 0.0435 mg.kg^{-1} (Fig. 8). The lowest was measured at the locality of Čierny Váh, the 1st sampling point - 0.01683 mg.kg^{-1}. Mercury concentrations show a lesser degree of variance at Čierny Váh than Veľký Choč.

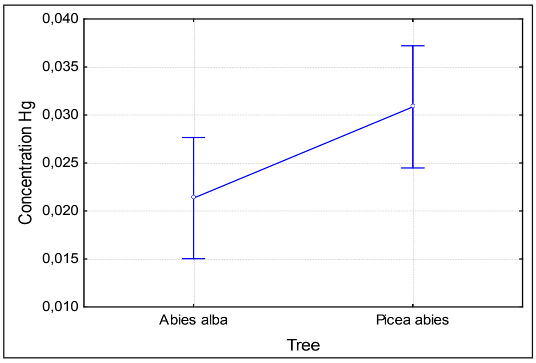

Fig. 8. The differences in mean Hg concentrations between *Picea abies* and *Abies alba* (F(1, 113)=4.4110, p=.03793; 0.95 confidence intervals).

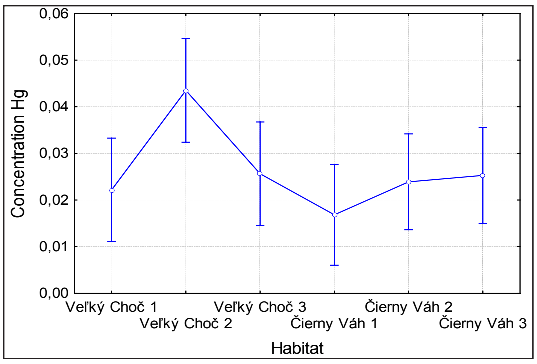

Fig. 9. The difference in Hg concentration between the locality near Veľký Choč and Čierny Váh (F(5, 109)=2.6479, p=.02673; 0.95 confidence intervals).

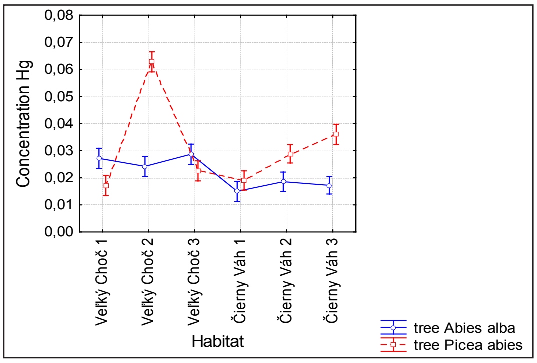

Fig. 10. Comparison of Hg contents between *Abies alba* and *Picea abies* in all sampling sites (F(5, 79)=46.095, p=0.0000; 0.95 confidence intervals).

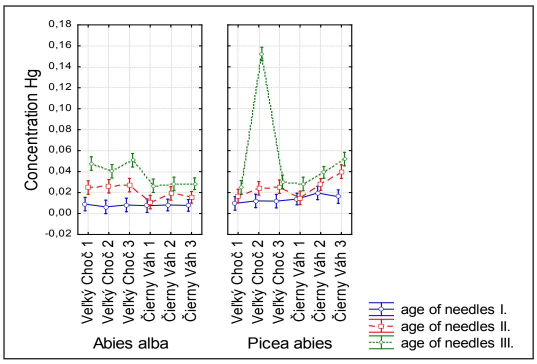

Fig. 11. The mercury concentrations increase with the age of needles.

The mercury contents are lower in *Abies alba* and higher in spruce at the locality Čierny Váh at all three sampling sites. In the locality of Veľký Choč, there are higher mercury values for the first and third sampling point for *Abies alba* as well as the second sampling site for spruce (Fig. 9).

The highest mercury concentrations were found in 3 year old Norwegian spruce (*Piecea abies*) needles at the second sampling site of Veľký Choč (Fig. 10). The values in the first year needles of the *Abies alba* are comparable between both samplig sites while the two-year needles of the *Abies alba* show higher values than those in Veľký Choč. The same applies to the 3 year old fir needles sampled. Annualy, spruce needles show higher mercury values at Čierny Váh, with two-year and three-year needles alternating.

Discussion

In order to assess environmental mercury contamination, we took samples of soil from a depth of 10 - 30 cm from two locations at Veľký Choč and Čierny Váh. In Slovakia, marcury values in soil vary between 0.02 and 0.2 mg.kg^{-1} (Beneš and Pabianová 1987). Ďurža and Khun (2002) measuered mercury concentrations at 0.098 mg.kg^{-1}. Steinnes (1997), measured global surface soil concentrations of Hg ranging from 0.003-4.6 mg.kg^{-1}. In our study conditions according to Act 220/2004 Coll. on the protection and use of agricultural land, the limit value of mercury for clay is set at 0.75 mg.kg^{-1}, 0.50 mg.kg^{-1} for clay soils, and 0.15 mg.kg $^{-1}$ for sandy and clay-sand soils. When we compare the measured values with the given limit, we conclude that the monitored locations did not exceed the limit value. The locations examined are not contaminated with mercury. Real Hg values in soil are likely to be of anthropogenic origin including cross-border emission transfer, the Mondi SCP pulp and paper mill, and the SlovTan facility for the manufacture, treatment, and processing of leather. Mercury concentration in soil in Slovakia was addressed by Maňkovská (1996a). The highest concentration was measured in Rudňany (130μg Hg/g), where in the years 1332 - 1992 mercury, iron, and copper were mined. According to Kabata-Pendias and Pendias (1992), Hg values are low, mostly ranging from 0.05 mg.kg^{-1} to 0.30 mg.kg^{-1}. According to Čurlík and Šefčík (1999), contaminated soils in Slovakia are present near Volovských vrchoch (lower and middle Spiš). Increased concetrations of mercury on the soil surface occur through the accumulation of mercury from the subsoil, as well as through contamination by emissions. At higher altitudes in northern and north-western Slovakia, mercury values in blanket humus are significantly increased due to long-range transmission by air pollution. Barančíková (1998) determined that mobility of mercury is dependant on pH. Alloway (1990); Barančíková (1998); and Berghofer *et al.* (1996) report that organic materials in soil have excellent absorption properties that affect the bioavailability of metals; particularly those with a high affinity for organic matter like copper and lead (Passdar 1994). According to measurements by Pavlenda *et al.* (2008) the concentration of mercury in the Ool subsiol of blanket humus varied from 0.024 to 0.831 mg.kg^{-1}. In the Oof subhorizon values of 0.057 to 9.518 mg.kg^{-1} were recorded. Glevaňák (2011) also measured mercury in soil, and the highest mercury values were recorded at the locality of Pod Briou in the Zamagurie region at 0.1185 mg.kg^{-1}. Maliková (2013) detected the highest concentration of mercury at the locality of Klokočov (0.114 mg.kg^{-1}) in area of CHKO Kysuce. Pacherová (2010) measured the highest concentrations of mercury in soil in near Štiavnické vrchy in the locality of Podlužany at 0.137 mg.kg^{-1}. Janotíková (2015) recorded the highest concentration of mercury 0.64096 mg.kg-1 at Hnúšťa. This area is located near former chemical plants for rubber production. Filipiak (2009) recorded values of Hg in the range of 0.061-0.287 mg.kg^{-1} near Brezno. The accumulation of mercury in soil horizons may be related to the absorption of Hg by humic substances and the formation of organomineral complexes. On the other hand, due to its volatility (elemental mercury), organic soil horizons have a higher concentration of mercury than mineral horizons. Fostier *et al.* (2000) found that precipitation passing through the crown layer may have up to 3 times the concentration of mercury compared to free surface precipitation. This phenomenon may be due to the washing of mercury trapped on the tree assimilation organs and the subsequent accumulation in the humus horizon (Rea *at al.* 2000). Plants can accumulate these pollutants substances in their root systems. Since *Abies alba* has a deep root system, we can assume that the accumulation of toxic substances instead takes place through the leaves by aerosols. Maňkovská (1996a) in Slovakia measured 0.1080 mg.kg^{-1} of mercury in the needles of *Abies alba*. Maňkovská (1996) measured the concentration of Hg in the needles of norwegian spruce from Rudňany (1.249-4.402 mg.kg^{-1}). According to Maňkovska (1996) the recommended Hg values for assimilation organs is 0,12 mg.kg^{-1}. Rea (2002) recorded growth concentration of mercury in assimilation organs at the end of the growing season in October (0.0360 – 0.0080 mg.kg^{-1}). At the beginning of the vegetation period in May, the concentrations were significantly lower (0.0035-0.0013 mg.kg^{-1}). In Spiš and also in Horná Nitra, Hg values were measured in assimilation organs of *Fagus sylvatica* at 4.01 mg.kg^{-1} (Maňkovská 1996a; Bodiš and Rapant 1999). According to Eriksen *et al.* (2003) Hg values in plant leaves are a function of time and of mercury concentration in the air and do not depend on the mercury concentration in the soil. Maňkovská (1984) measured concentration of Hg 0.12 mg.kg^{-1}. Near the Biosphere Reserve Poľana, Kontrišová *et al.* (2004) measured mercury concentrations of 0.0373 mg.kg^{-1} in two-year needles of *Picea abies*. At Mlynky in Slovenský Raj, Kontrišová *et. al.* (2004) recorded the lowest values (0.0399mg.kg^{-1}) in one year old needles of *Picea abies*, and the highest values in two year old needles of *Picea abies* (0.0842 mg.kg^{-1}). Kontrišová *et al.* (2004), in the mid-Pohron region Prestavlky recorded average values in one year old needles of *Picea abies* (0.0345 mg.kg^{-1}) and higher values in two year old needles (0.0451 mg.kg^{-1}). In 1996, the values of mercury in needles stabilized at 0.1 mg. kg^{-1} (Maňkovska 1996a). Janotíková (2015) measured the highest concentration of mercury in the locality of Hrachovo at 0.02971 mg.kg^{-1}. Kubinčanová (2014) recorded mercury values of 0.0563 mg.kg^{-1} in second year needles for CHKO Kysuce measured at the locality of Nová Bystrica. Maňkovská (1996a) measured average values of mercury in *Picea abies* needles in Horná Nitra at 0.099 mg.kg^{-1}, in Žiar nad Hronom at 0.076 mg.kg^{-1}, in Bratislava at 0.089 mg.kg^{-1} and in Košice at 0.133 mg.kg^{-1}.

Acknowledgements

I thank to Dr. Haas for her patience, and moral support in writing this article. I would like to thank my parents who supported me throughout the study.

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Recieved 13 August 2019; accepted 11 November 2019.