Investigation of heavy metals transportation from soil to the pine tree

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Abstract The Scots pine (Pinus sylvestris L.) is the most common tree in Lithuanian forests. Research on the impact of pollutants on pines allows us to evaluate pollutants in a major part of Lithuanian forests. Heavy metals (HMs) are among the major pollutants entering forest ecosystems in different ways: in their wet and dry form they come from local or distant sources of emission by being transported from seas alongside with nutrients and sea salt, washed up from the dead plants accumulated in soil, and together with mineral particles brought by wind or water. During the period of investigation, a decrease in the Cr concentration in pine rings is seen. High Zn concentrations (in 1987–1989 Zn concentration was 27.6 mg·kg⁻¹) in the pine may be caused by emissions from heavy traffic. The results have shown that Mn has the highest concentration as compared with that of other HMs in the soil around the pine (at the depth of 30–40 cm, Mn concentration is 780 mg·kg⁻¹). In comparison with other HMs, Cu and Zn have the largest factor of transport from the soil to the wood (0.39 and 0.49 respectively).

Keywords Heavy metals; heavy metals in soil; military territories; plant uptake; tree rings

Introduction
The Scots pine (Pinus sylvestris L.) is the most common tree in Lithuanian forests. Research on the impact of pollutants on pines allows us to evaluate pollutants in a major part of Lithuanian forests. Forest ecosystems have different pollutant sensibility (Ozolinčius, 1999; Ekvall et al., 2002; Loppi et al., 2002). Heavy metals (HMs) are among the major pollutants entering forest ecosystems in different ways: in their wet and dry form they come from local or distant sources of emission by being transported from seas alongside with nutrients and sea salt, washed up from the dead plants accumulated in soil, and together with mineral particles brought by wind or water (Nord Atmospheric, 1996). A lot of data on HM migration and accumulation in the forest soil, moss, and water are available in literature but information on HM accumulation in tree rings is scarce.

A major part of HMs is taken up by the tree from the soil via its roots (Martin et al., 1982; Ozolinčius and Stakėnas, 1998; Walkerhorst et al., 1996). HM transportation from the soil to the roots largely depends on the type and genetic features of soil forming rocks, granulometric soil composition, amount of organic matter, pH of the soil, sorption capacity, amount of CaCO₃, anthropogenic load, and other chemical and physical properties of the soil (Yatti et al., 1991; Vačys et al., 1999). HM mobility in the soil has impact on their transfer to the tree roots. It has been determined that Cr has low mobility in the soil, and it accumulates in moderate concentrations in marshy soil and low swamp turf (Ozolinčius, 1999; Kadušas et al., 1999). Cr can be transported by the atmospheric air over a long distance and is one of the pollutants emitted by the heavy industry (Loppi et al., 2002).

Cu is most mobile of HMs, but its uptake by plants is slow (Aąkaceveb, 1987). It has been determined that Cu, like Cr, is also the transport-emitted pollutant (Loppi et al., 2002). Pb, Mn, Ni and Zn mostly accumulate in the turfy soil forest litter. Their concentration exceeds that in the upper layers of the soil (Mažvila, 2001). It has been determined that the concentration of Mn, as opposed to that of Zn, in the forest soil is higher than in other soils.
(Kadūnas et al., 1999). It has been calculated that the HM concentration in sand and sandy loam soils is 2–4 times lower than that in loam and clay soils. This explains the capability of clay minerals to effectively absorb HMs (Kadūnas et al., 1999).

The aim of this work is to analyze Cu, Cr, Pb, Mn, Ni and Zn accumulation in the rings of the pinewood and in the soil around the pine as well as to determine the transport factor of the investigated HMs, which could allow us to determine the part of HMs amount in the pinewood taken up by roots from a different depth of the soil.

Methods

Sampling

The research was carried out on pine – the tree prevailing in Lithuanian forests. The investigated pine (16-m high, 44-year-old, 0.4 m thick) grew on the Military Ground of Rukla–Gaizūnai (Jonava District, Lithuania), not far from water bodies used for military training.

Wood Sampling. First of all, 5 cm long rolls were cut away from the trunk. Samples were taken from the upper part of the tree (3/4 of the trunk height) (P3), the middle of the tree (P2), and the bottom part of the trunk (P1)(1m from the stump).

Soil samples were taken around the pine following the scheme illustrated in Figure 1.

To evaluate the dependence of the HM concentration on the soil depth, the samples were taken from the soil layers at the following depths: 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm.

The soil on the Military Ground of Rukla–Gaizūnai is sod-podzolic or medium sod-podzolic, its average acidity is approximately 5.5 pH. The relief is hilly (the grade is 3–5%). The forest floor is 5–7 cm thick. The average annual temperature in this region is +6°C. The highest earth freeze depth is 1.25 m. The prevailing wind is southwest. The average annual rainfall is 590 mm.

Sample preparation

Wood samples. The cut wood rolls were split into slivers in the direction of the tangent around the rings. Slivers were formed into samples that were dried out and burnt. The mass of a wood sample was 30–40 g. Samples were burnt in ceramic vessels in a muffle furnace.
at 480°C for two hours. The slivers were weighed prior to burning, and after burning the ash was weighed.

**Soil samples.** The soil was ground, mixed and screened (the average mash diameter was 1 mm). The mass of each soil sample was 30 g.

**Chemical analysis of samples**

**Wood samples.** 0.5–1.0 g samples were formed of the wood ash. The ash of each sample was put into a heat resistant glass vessel and kept there for 24 hours poured over with 100 ml of 20% nitric acid. If it took long for the ash to fully dissolve, the solution was boiled in a draught hood for up to 15 min. The solution was filtered and diluted with 2% nitric acid. A parallel procedure was used for preparation of the sample containing no ash, which was used as a control one.

**Soil samples.** Soil samples of 30 g were heated at 100°C for 2 hours for the moisture to evaporate. The samples were cooled to the room temperature and weighed (25 g of each sample). Later, in the course of 3 hours, the organic compounds still remaining in the soil were completely burnt at 450°C. Then the samples were dissolved in 20% nitric acid and boiled in a heat resistant glass vessel in a draught hood for 15 min. The hot solution was filtered and diluted with 2% nitric acid. A parallel procedure was used for the control sample preparation.

The HM concentration in wood and soil samples was determined with Buck Scientific atomic absorption spectrophotometer 210VGP.

**Results and discussion**

Figure 2 shows that the variation in the HM concentration in the annual rings of the pine is diverse and uneven. During the investigated period (1981–2001), a decrease in the Cr concentration is seen. This might imply the radial migration of Cr to the deeper layers of the wood. A significant increase in its concentration in 1981–1983 could be influenced by the increase in the Cr concentration in the air. It has been determined that Cr can be transported by the atmospheric air over a long distance and it is one of the pollutants emitted by the heavy industry. Figure 2 shows that the Cr concentration in the pine that grew on the Military Ground of Rukla–Gažiūnai about 2–5 times exceeds that in the wood of the pine that grew in a similar soil type in Alytus District (Lithuania). The results can prove the theory that, in comparison with its migration in the radial direction, the larger part of Cr is taken up by the pine from the environment (Baltreńaitė et al., 2002).

The Cu concentration, that in 1981–2001 had undergone uneven changes, reached its peak (2.59 mg·kg⁻¹) in 1999–2001. Cu is one of the transport-emitted pollutants, thus its increase has confirmed that the traffic within the investigated area is really heavy. Moreover, the pine grew close to ponds used for military training, thus assumed part of Cu dissolved in water could reach the roots of the pine.

The low Pb concentration in the pine rings could be explained by the lower Pb concentration during the period of research, as it is considered that part of Pb could be transferred to the wood via leaves, bark, and small branches.

It has been found that accumulation of Mn in the pine is intensive. The soil pH in the investigated area is 5.5 and this is a favourable media for Mn accumulation in the form of a soluble dyad and exchangeable salt. This might be the reason for an increase in the Mn concentration in the pine rings of the period 1981–1983 up to 82.45 mg·kg⁻¹.

High Zn concentrations (in 1987–1989 Zn concentration was 27.6 mg·kg⁻¹) in the pine rings may be caused by emissions from heavy traffic, as Zn, like Mn and Cu, are the...
elements of transport emissions. Besides, it is known that military transport routes and manoeuvre fields are installed not far away from the growth place of the pine.

Figure 3 shows that Mn has the highest concentration of the HMs in the soil around the pine (at the depth of 30–40 cm, Mn concentration is 780 mg·kg⁻¹) (Figure 3). This reveals that Mn is mobile not only in the pinewood but also in the soil; and its large amount is taken up by the tree from the soil. Along the soil depth, an apparent decrease in Pb concentration is seen (Figure 3). The highest concentration of this HM in the soil was recorded at the depth of 0–10 cm (9.48 mg·kg⁻¹), i.e. in the surface layer having the largest part of humus, which has an effective impact on the Pb stabilization (Baltreñaite et al., 2002).

A high concentration of Cr (on the average, about 6 mg·kg⁻¹) may be influenced by the activity of local industry and the pollutants which are emitted and brought by the atmospheric air.

The transport of the HM concentration from the soil to the tree is expressed by the transport factor. It is a non-dimensional value and was calculated dividing the calculated HM
concentration in the pine rings (1999–2001) by HM concentration at different layers of the soil.

Figure 4 illustrates the change of the transport factor, when it is calculated at a different depth. However, Figure 4 shows that in case of Ni the transport factor increases to 2.30. A very high transport factor of Ni was obtained because Ni accumulation in the pine wood is also influenced by Ni migration from leaves or bark.

The transport factors of Cu and Zn are higher than those of other HMs. The average transport factor of Cu is 0.39, and that of Zn is 0.49. The transport factors of Cr and Mn are much lower, i.e. 0.01 and 0.03 respectively. This could be explained by the fact that Cr and Mn are very mobile in the soil. This could account for a rather moderate Cr concentration in the pine rings (0.34 mg·kg\(^{-1}\)). High Mn concentrations in pine rings may imply Mn accumulation in the wood.

**Conclusions**

The Scots pine (*Pinus sylvestris* L.) is one of the most common trees in Lithuanian forests. Thus the research of the pollutants’ impact on the pine allows us to evaluate pollutants in a major part of Lithuanian forests. During the investigated period (1981–2001), a decrease in the Cr concentration in pine rings is seen. This might imply the radial migration of Cr to the deeper layers of the wood. A low Pb concentration in the pine wood could be explained by a lower Pb concentration during the period of investigation, as it is considered that part of Pb could be transferred to the wood via leaves, bark, and small branches. High Zn concentrations (in 1987–1989 Zn concentration was 27.6 mg·kg\(^{-1}\)) in the pine may be caused by emissions from heavy traffic, as Zn is one of the elements of transport emissions. Besides, it is known that military transport routes and manoeuvre fields are installed not far away from the growth place of the pine. The results have shown that Mn has the highest concentration than that of other HMs in the soil around the pine (at the depth of 30–40 cm, Mn concentration is 780 mg·kg\(^{-1}\)). This shows that Mn is mobile not only in the pinewood but also in the soil, and its large amount is taken up by the pine from the soil. The highest concentration of Pb in the soil was recorded at the depth of 0–10 cm (9.48 mg·kg\(^{-1}\)), i.e. in the surface layer having the largest part of humus, which has an effective impact on Pb stabilization. Cu and Zn undergo the greatest transport to the pine from the soil. The average transport factor of Cu is 0.39, and that of Zn is 0.49.
References


