2 The Method of Dynamic Factors in Bioindication and Phytoremediation

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2.1 Introduction

Complicated mechanisms of the accumulation of chemical elements in plants are depicted in scientific literature for at least 60 years, whereas their practical usage in exploration geochemistry is applied for over 70 years. The chemical composition of plants (as well as of all other organisms) depends upon three main factors: their systemic position, environment (the composition of soil, rock, etc.), and individual peculiarities of the plant (first of all, of their evolutionary stage). Furthermore, separate organs of the plants (roots, trunks or stems, leaves, seeds or fruit, etc.) are distinct by the qualities of their composition with regard to chemical elements (Lietuvninkas 2012; Marozas et al. 2013).

The main factors of chemical element concentration in plants, with regard to plants, are normally subdivided into internal (physiological) and external (ecological). Among the external (ecological) factors, the concentration of chemical elements in the nutrient medium (in soil in the case of plants) and the availability of a chemical element to plants have the greatest influence. It depends upon a large number of interrelated factors: the chemical and geochemical characteristics of a chemical element, the parameters of its environment (pH, Eh, temperature), the presence or absence of geochemical barriers, climate, the geochemical characteristics of the landscape, etc. The level of bioaccumulation is governed by lighting conditions for plants. Internal (physiological) factors encompass specific biochemical barriers that are characteristic of some plants, as well as the plants' classificatory position, species, phases of vegetation, and organs (Kovalevsky 1987; Dobrovolsky 2008).

In the latest publications, plant tolerance with regard to chemical elements is associated with two directions of their perception in plants: immunity (resistance) when they are eliminated by plants or immunity (resistance) when they are assimilated and later immobilized in the cells together with the immobile forms (Prasad 2006; Shaw et al. 2006). Actually, the issue is far more complex because separate organs of plants (roots, trunks and stems, leaves, reproductive organs) under the same conditions accumulate chemical elements differently—the acro- and basipetal types of chemical element accumulation (Kovalevsky 1987; Pulford and Dickinson 2006). These aspects are not going to be discussed in this paper. We will confine to the ability of plants to accumulate a larger or smaller amount of chemical elements under certain conditions with regard to the background. This may be used both to evaluate their environmental condition (bioindication) and to rehabilitate a contaminated soil (phytoremediation).

Bioindication and phytoremediation are applied aspects of the accumulation of chemical elements in plants. Bioindication is a means of contamination indication that is most widely investigated in Lithuania and the whole world. Plants most commonly used for heavy metal bioindication are the following: Scots pine (*Pinus sylvestris* L.), silver birch (*Betula pendula*), European ash (*Fraxinus excelsior*), European mountain ash (*Sorbus aucuparia*), small-leaved lime (*Tilia cordata*), and domestic apple (*Malus domestica*) (Kupčinskienė 2011; Stravinskienė 2010, 2011; Butkus and Baltrėnaitė 2007a). Some of the most important directions of fields in Lithuania are discussed in Sect. 2.2.

Phytoremediation, when using trees to rehabilitate contaminated with heavy metals has several relevant advantages: a large biomass of trees, genetic variety, and successful forestry, converting biomass into fuel by means of anaerobic decomposition, fermentation, or thermochemical processes; positive attitude of the society towards afforestated territories; and stability of those territories when dealing with erosion caused by wind and water (Pulford and Dickinson 2006).

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To summarize, it may be stated that plant-based methods of environmental bioindication and environmental quality improvement would receive more approval from the interested parties if they assumed a clear quantitative expression of bioindication.

The aim and content of this paper is to present investigations on the application possibilities of chemical composition qualities of higher plants that have been carried out in Lithuania, as well as to introduce a new evaluation method for chemical element uptake from soil to plants and within plants, applying **the dynamic factors of bioaccumulation, biophilicity, phytoremediation, and translocation**.

2.2 Aspects of Applying the Scots Pine (*Pinus sylvestris* L.) and Other Trees for Bioindication and Phytoremediation of Metals in Lithuania

Trees are qualified as sensitive indicators of the environment condition (Cook and Kairiūkštis 1999; Stravinskienė 2010; Kupčinskienė 2011). The Scots pines (*Pinus sylvestris* L.) are most widely spread compared to their congeners. The whole territory of Lithuania accesses the habitat of the Scots pines (Navasaitis et al. 2003; Navasaitis 2008). Due to the wide distribution and usually non-barrier type of absorption of variety of contaminants, *Pinus sylvestris* L. is suitable for monitoring changes in the environment. As the academician L. Kairiūkštis (Cook and Kairiūkštis 1999) states, the dendrochronological and dendroindicational methods of environment analysis are the theoretical basis for searching the evaluative criteria for the anthropogenic effect on the forest ecosystems and growth of trees.

With increase of environmental pollution, this problem is examined more widely, and the issues of the influence of xenobiotics on organisms, the significance of contamination uptake through the food chain, and the usage of plants for engineering solutions in the environmental security (phytotechnology) are discussed; therefore such contaminants as heavy metals (i.e., remaining in the nature for a long period of time, a large part of which, according to the biochemical role, are toxic) have gained great significance. Also, a lot of attention to metals has been paid in the following international scientific programs and conferences: *COST* 859 *Phytotechnologies to Promote Sustainable Land Use and Improve Food Safety*, *COST FA* 0905 *Mineral Improved Crop Production for Healthy Food and Feed*, *SETAC*, *TRACEL*, and *ICOBTE*.

In the analysis of the uptake of heavy metals from soil into the Scots pine wood, carried out in 2001 in Lithuania, a number of more important pathways of metal (Ni, Cu, and Zn) uptake by the Scots pine have been evaluated in the Rukla–Gaižiūnai (Jonava district) and Kairiai (Klaipėda district) military grounds; they are air–pine bark; air–soil–pine wood, and soil–pine wood. Zn concentration about four times above the average has been found in wood samples from the Scots pines that grew near the shooting range. This could be explained by the fact that Zn concentration in the shooting range soil is three times higher than the average concentration in that territory. About five times higher concentration of Ni and about three times higher concentration of Cu have been found in wood samples from the Scots pine near a water body that was used for military purposes. Ni and Cu might have got into the atmosphere and precipitate on the bark of the trees as constituents of fuel; they also might have got onto the soil together with rainfall and through roots—into the wood (Butkus and Baltrėnaitė 2007a). The local increase of metal concentration in the environment is also confirmed by the fact that concentration of Cu and Ni found in the water body exceeds the highest permissible concentration for drinking water 19 and 22 times, respectively (Baltrėnas et al. 2005). In the bark samples of the Scots pine that grew in this area, concentration of Cu has been found about 1.3 times higher than the average concentration of other pines that have been analyzed (1.75 mg/kg); the concentration of Ni detected was two times higher (4.56 mg/kg) (Butkus and Baltrėnaitė 2007a). This justifies the application of the Scots pine's property to accumulate more metals in its bark in various countries, such as Portugal, Jordan, Germany, Finland, Czech Republic, and the United Kingdom (Machado et al. 2006; Schulz et al. 1999; Harju et al. 2002). This phenomenon is also investigated in Lithuania (Butkus and Baltrėnaitė 2007a; Pundytė and Baltrėnaitė 2011; Baltrėnaitė et al. 2014).

In 2005 investigations were carried out in the territory of a former forest; they took place 7 years after sewage sludge, contaminated with heavy metals, was spread on the soil and 6 years after planting the trees (*Pinus sylvestris* L.; *Betula pendula*; *Alnus glutinosa*). Air contamination with metals in that area was not detected. The main uptake of metals was most probable in the system *soil–tree*. Concentration of Cu and Pb was approximately six times higher and of Ni four times higher in the Scots pine than in the black alder. Concentration of Cu was 2.5 times, of Pb 4 times, and of Ni 3 times higher in the Scots pine than in the silver birch. Compared to control samples, the concentration of these metals in the Scots pine was about five times higher. These investigations allowed assuming that the spread of metal-contaminated sewage sludge in the soil stimulates the accumulation of metals in the seedlings during the first 6 years after planting. Concentration of Ni, Pb, and Cu in the Scots pine can moderately reach up to five times higher values compared to control trees and from two to six times compared to the silver birch and the black alder (Butkus and Baltrėnaitė 2007b; Baltrėnaitė and Butkus 2007).

Such results encourage continuing to regard trees as a potential option when phytoremediation is preferred and when seeking to eliminate or stabilize contamination. On the other hand, it has been observed that sewage sludge, contaminated with heavy metals, does not stimulate rapid increase of the wood biomass. After having evaluated the increase of the biomass in the same territory after 10 years time, the difference between the control trees and trees that grew in the soil with applied sewage sludge was not statistically significant. It has been found that the increase of the Scots pine biomass was by 87 % larger than that of the silver birch, and the accumulated Cu, Cd, and Pb concentration in the Scots pine biomass was higher than that in the silver birch by approximately 60 %. This analysis allowed inspecting two tree functional trait groups of the Scots pine and the silver birch: better nutritional qualities of the soil can be better identified by the increase of the specific root length (SRL), the reduction of the root–shoot ratio and wider root branching, whereas the effect of potential heavy metals can be better identified by a lower height of the trees, the trunk diameter, and the dry biomass (Vaitkutė et al. 2010).

Analyses of element concentration (Pb, Cu, Zn, K, and Mg) in the wood of *Pinus sylvestris* L. that have been carried out in a formerly intensive industrial territory (Panevėžys, Lietuva) have confirmed that Scots pine has the qualities to biomonitor aerogenic metals. Compared to the control site, concentration found in the wood of the Scots pine was higher: Cd ($p<0.05$) about two times higher, Zn ($p<0.001$) and Cu ($p<0.05$) about 1.5 times higher, K ($p<0.05$) 1.3 times higher, and Mg ($p<0.05$) 1.9 times higher (Pundytė and Baltrėnaitė 2011; Pundytė et al. 2011).

Trees are affected not only by anthropogenic, but also by natural (abiotic and biotic) factors, which often become stressors. Tree diseases, as a biotic factor/stressor, as well as the interaction of the tree and the pathogen, gain relevance in the understanding of natural resistance and the biochemical aspects of this concept. *H. annosum* is known as a dangerous rot pathogen of the main roots of a tree, which further damages the conifer wood. In 1999 it had damaged approximately 1.2 thousand hectares of pine forest (Navasaitis et al. 2003). During the analysis of a damaged pine wood composition, in the tree ring of 1959–1960, the concentration of Ni and Cr was about five times higher than in other tree rings. In this tree ring, according to the micromorphological symptoms of the mycelium, the root rot pathogen's mycelium has been detected. The increase of Ni and Cr concentration in the damaged wood can be explained by the tree's resistance to the disease, when the concentration of metals increased to fight the disease pathogens (Poschenrieder et al. 2008). When the pathogen gets into the wood, it destroys its constituent part—lignin—in order to reach cellulose which is in the cell walls and which is a very important source of energy. Stress, caused by these processes, stimulates the tree's protective functions. It is probable that metals also take part in the protective reactions. It is known that Ni improves metabolism because while accumulated on the cell walls, it enhances their permeability, and Cr is necessary for the production of glucose, from which glucoside and lignin are formed. Although these data are primary, they allow suggesting that the changes in metal concentration can identify biotic and abiotic factors/stressors that affect trees (Baltrėnaitė and Butkus 2006; Vaitkutė and Baltrėnas 2011).

The effect of other contaminants on pines and other trees in Lithuania has been discussed in the following works: Stravinskienė and Dičiūnaitė (1999), Juknys et al. (2003), Juknys et al. (2006), Kupčinskienė (2011), Ozolinčius et al. (2005), Augustaitis et al. (2007a, b), Augustaitis and Bytnerowicz (2008), Butkus et al. (2008), Stravinskienė and Šimatonytė (2008), Stravinskienė and Erlickytė-Marčiukaitienė (2009), Baltrėnaitė et al. (2010), Pliopaitė Bataitienė and Butkus (2010), Stravinskienė (2010), Stravinskienė (2011), Baltrėnas and Vaitkutė (2011), Pundytė et al. (2011a, b), and Markert et al. (2012).

This paper will further concentrate on metals and their uptake and translocation in trees, although the presented evaluation method based on dynamic factors can be applied in the cases of all other chemical elements and trees.

2.3 Dynamic Factors in Evaluations of Bioindication and Phytoremediation

2.3.1 The Concept of Dynamic Factors

The fields of bioindication and phytoremediation require evaluating the processes of the absorption of chemical elements by the plants, in order to compare the plants by their capacity to absorb chemical elements and to compare the chemical elements by their possibilities to get into the plants. The changes in uptake of metals by plants, which depend upon the plant species and the genotype, are elaborately described by Prasad (1997), Brooks (1998), and Prasad and Hagemeyer (1999). However, besides the biochemical viewpoint, the biogeochemical attitude is also of great importance. The latter is concentrated on the link between plant and its environment, firstly the soil.

The interface of the soil and a plant is the main criterion when evaluating the peculiarities of the concentrative function of the plant. The basic parameters of the soil, which control metal uptake by plants, are different subject to the native rock, landscape, type of ecosystem, and soil modification, and altogether they determine the processes of metal mobility and uptake by plants. These parameters are as follows: pH; Eh; CEC; the content of clay particles and the organic material in the soil; the concentration of Fe, Mn, and Al oxides and hydroxides; the variety and abundance of microorganisms; and finally, the proportion of the mobile forms of metals which are being evaluated. The interface of the soil and a plant, or in other words, the concentration of metals in a plant with respect to the soil, is the basis for a widely used Biological Absorption Coefficient (BAC), also known as Index of Bioaccumulation (IBA), Transfer Factor (TF) (Kabata-Pendias 2010), Transfer Coefficient (TC) (Antoniadis et al. 2006), Bioaccumulation Factor (Prasad 2006), Mobility Ratio, (MR) (Mingorance et al. 2007; Baker 1981; Chamberlain 1983), Bioconcentration Factor (BCF) (Pulford and Dickinson 2006; Gál et al. 2008; Yoon et al. 2006), or Plant–Soil Coefficient[1] (Kovalevsky 1987), which is expressed by the proportion of metal concentration in a plant and soil. This ratio indicates qualities of metal absorption by plants (when the value of the ratio is more than one, plants are termed as accumulators; when the value is close to or equal to one—as indicators—when it is less than one—as excluders), the degree of metal hazard as well as risk assessment for biota. In Russia, bioaccumulation sequences of metals and other chemical elements have been created by B. Polynov and later on improved by A. Perelman (1989). Chemical elements were divided into four groups according to their uptake: *elements of vigorous uptake (P, S, Cl, Br, I), of strong uptake (Ca, K, Mg, Zn, Se, etc.), of medium uptake (Mn, Ni, Cu, Co, Pb, As, Hg, etc.) and of weak/very weak uptake (V, Cr, Sb, Cd, etc.).* Mingorance et al. (2007) used the Enrichment Factor (EF) to evaluate the accumulation of metals and other chemical elements in the analyzed soil and plant, comparing it to the control objects.

Although the abovementioned factors/coefficients express the uptake of metals into the plant in relation to the soil, they do have some disadvantages. From the biogeochemical point of view, they provide a comparison of metal concentration in different media (plant and soil), but only in a particular place (with its typical environmental conditions) or at a particular time (e.g., 10 years after the sewage sludge had spread on the soil). ***Firstly***, it would be inaccurate to compare different plants according to the abovementioned factors/coefficients in the biogeochemical respect, because they may have grown under different circumstances, in different soil and in different elementary landscape, and these facts determine the diverse qualities of metals (and other chemical elements) mobility and uptake. ***Secondly***, the necessity arises to compare not only metal concentration in the plants to metal concentration in the soil or in the control plant but also to compare the changes in the metal uptake processes and the intensity, compared to the control case. Moreover, in order to evaluate the process (in this case, the uptake of chemical elements), it is also necessary to compare the processes, not the concentration. ***Thirdly***, there is a lack of comparative proportion between the metal uptake by the plant and the control case, expressed in numbers, which would facilitate the evaluation of metal uptake. ***Fourthly***, the integration of the effect of natural processes, which have influence on the metal uptake, is very important. These goals can be achieved by using second-level factors[2]. They are calculated by comparing the value of the uptake factor in the territory of investigation to the corresponding factor value in the control territory.

We proposed to use the second-level factors to describe four types of the metal behavior in plants after soil modification. The factors are called the *dynamic factors*[3] because they are sensitive to changes of variables that are involved in calculation.

The dynamic factor of metal bioaccumulation (BA_{dyn}) reflects the physiological sensitivity of plants to the general soil contamination degree [Eq. (2.1)]:

$$BA_{dyn} = \frac{C^i_{T\_t} \times C^i_{S\_c}}{C^i_{S\_t} \times C^i_{T\_c}}, \quad (2.1)$$

where $C_{T\_t}{}^i$ concentration of metal *i* in tree wood ash on the treated site, mg/kg; $C_{S\_t}{}^i$ concentration of metal *i* in the treated soil, mg/kg DW; $C_{S\_c}{}^i$ concentration of metal *i* in the control soil, mg/kg DW; and $C_{T\_c}{}^i$ concentration of metal *i* in the control tree wood ash, mg/kg.

The dynamic factor of metal translocation reflects the changes in metal translocation from plant roots to vegetative organs [Eq. (2.2)]:

$$TR_{dyn} = \frac{C^i_{v\_t} \times C^i_{r\_c}}{C^i_{r\_t} \times C^i_{v\_c}}, \quad (2.2)$$

where $C_{v\_t}{}^i$ concentration of metal *i* in tree vegetative organs on the treated site, mg/kg DW; $C_{r\_t}{}^i$ concentration of metal *i* in tree roots on the treated site, mg/kg DW; $C_{r\_c}{}^i$ concentration of metal *i* in tree roots on the control site, mg/kg DW; and $C_{v\_c}{}^i$ concentration of metal *i* in tree vegetative organs on the control site, mg/kg DW.

The dynamic factor of metal biophilicity (BF_{dyn}) reflects changes in metal participation in plant metabolism [Eq. (2.3)]:

$$BF_{dyn} = \frac{C^i_{T\_t}}{C^i_{T\_c}}. \quad (2.3)$$

[1]The Plant–Soil Coefficient defines proportion of metal concentration in the plant's ashes and the soil. In the works of other researchers, the concentration of metal in the plant has been recalculated on the basis of dry biomass.

[2]There can be several levels of comparison of metal concentration in plants: (1) direct comparison of their concentration in biomass (incorrect because the concentration of respective metals in the soil that nourishes plants is not included); (2) bioconcentration (bioaccumulation) coefficients (the effect of higher or lower metal concentration in the soil on their uptake and accumulation in plants is not evaluated); (3) dynamic factors of bioaccumulation, which include the effect of soil metal concentration in control (background) and contaminated territories on their uptake and accumulation in plants.

[3]The concepts and calculations of dynamic factors correspond to Baltrėnaitė et al. (2012) of the reference list.

Generally, metal biophilicity is the ratio of metal accumulation in living biomass and metal concentration in the Earth's crust, and thus it indicates metal involvement in the metabolism on the global vegetation basis.

The dynamic factor of phytoremediation reflects changes in phytoremediation effect and phytoremediation capacities of plants [Eq. (2.4)]:

$$\mathrm{FR}_{\mathrm{dyn}} = \frac{C^{i}_{\mathrm{T\_t}} \times B_{\mathrm{t}} \times C^{i}_{\mathrm{S\_c}} \times \rho_{\mathrm{c}}}{C^{i}_{\mathrm{T\_c}} \times B_{\mathrm{c}} \times C^{i}_{\mathrm{S\_t}} \times \rho_{\mathrm{t}}}, \tag{2.4}$$

where B_t and B_c annual tree increment on treated and control sites, respectively, kg/ha; ρ_c and ρ_t soil density on treated and control sites, respectively, g/cm^3. Usually $\rho_c = \rho_t$.

If we rearranged Eqs. (2.1) and (2.4) and presumed that the soil density before and after the modification did not alter much ($\rho_c = \rho_t$), we would have an expression of the interface between the dynamic bioaccumulation factor and the dynamic bioremediation factor [Eq. (2.5)]:

$$\mathrm{FR}_{\mathrm{dyn}} = \mathrm{BA}_{\mathrm{dyn}} \times \frac{B_{\mathrm{t}}}{B_{\mathrm{c}}}. \tag{2.5}$$

Besides the biogeochemical meaning, the dynamic factors have practical advantages:

(a) They integrate four types of information—metal content between two mediums (or plant organs) and between reference and treated sites—into one value and thus make metal transfer evaluation less complicated.
(b) They are dimensionless and thus provide easy comparison.
(c) They eliminate systematic errors of analysis and thus improve the precision and quality of evaluation.

2.3.2 Dynamic Factors: Practice

Experimental analyses designed to establish the factors have been carried out in a former forest territory (Gitėnai forest Taruškos forestry, Panevėžys region, the western part of Lithuania, at E024°34′38.8″ latitude and N55°43′31.6″ longitude) where 14 years ago a part of the territory (2 ha) was modified with industrial sewage sludge. A site more than 200 m away from the modified site has been selected as the control site. A year after modification, the site was planted with Scots pines (*Pinus sylvestris* L.) and silver birches (*Betula pendula*). In natural conditions, black alders (*Alnus glutinosa*) sprout in the site. Samples of wood and soil were taken from the modified and the control sites. Six samples of each tree species were sampled (*Pinus sylvestris* L., *Betula pendula*, *Alnus glutinosa*); meanwhile in the tree growth place complex, soil samples were taken at a depth of 0–40 cm. The physical and chemical preparation of wood and soil samples has been accomplished according to the methodology depicted by Baltrėnaitė et al. (2012).

The statistical analysis of the data has been performed using *Microsoft Office Excel 2007*. The array of primary data has been evaluated according to the 3D criteria. To calculate the values of dynamic factors, the mean values of measurements were used. The dynamic factors, expressing metal uptake and translocation processes in the cases of the Scots pine, the silver birch and the black alder, are provided in Figs. 2.1, 2.2, 2.3, and 2.4. Columns reflect the values of dynamic factors that are larger than one, i.e., express increase with regard to the control site.

As it can be seen in Fig. 2.1, the $\mathrm{BA_{dyn}}$ values of the majority of metals were higher than one. Values below one were only found in the cases of Mn and Pb and only in the cases of the black alder and the silver birch (they cannot be seen in Fig. 2.1 because the *Y*-axis starts with 1). The highest value of $\mathrm{BA_{dyn}}$ was found in the Scots pine, and the highest value among metals was common for Ni in the case of the Scots pine ($\mathrm{BA_{dyn}} = 120.8$).

In the cases of almost all the metals (except Mn in the black alder), the dynamic factors of biophilicity ($\mathrm{BF_{dyn}}$) were higher than one (Fig. 2.2), i.e., the contamination of the soil with heavy metals increased their biophilicity and metal concentration in plants, compared to metal concentration in the soil. The Scots pine also was distinct for its highest values of $\mathrm{BF_{dyn}}$ for all analyzed metals.

Opposite tendencies emerged regarding the dynamic translocation factor ($\mathrm{TR_{dyn}}$): only the values of $\mathrm{TR_{dyn}}$ for Mn and Ni and only with regard to the black alder were higher than one (Fig. 2.3). In the cases of other metals, this factor indicated a decreased metal translocation in the contaminated site, compared to the control site.

The individual qualities of analyzed trees in respect of phytoremediation are reflected by the dynamic phytoremediation factor ($\mathrm{FR_{dyn}}$): it was the highest in the case of the Scots pine and especially pronounced with regard to Pb (Fig. 2.4).

2.3.3 Advantages of Dynamic Factors

2.3.3.1 Dynamic Factors Allow Comparing the Changes in the Process of Metal Uptake by Different Plants (Trees), by Evaluating the Geochemical Features of the Analyzed Area

By using dynamic factors, not only plants can be compared on the level of their capacity to uptake metals, but also the changes in the process of metal uptake can be evaluated after soil modification, comparing the results to the control site, which must be identical in other geochemical respects, except the fact of modification.

In our investigation, after soil modification with sewage sludge, the Scots pine was distinct from the three tree species of investigation. Compared to the control site, the metal uptake became more intense in the Scots pine than in the silver birch or in the black alder. This was indicated by higher values of

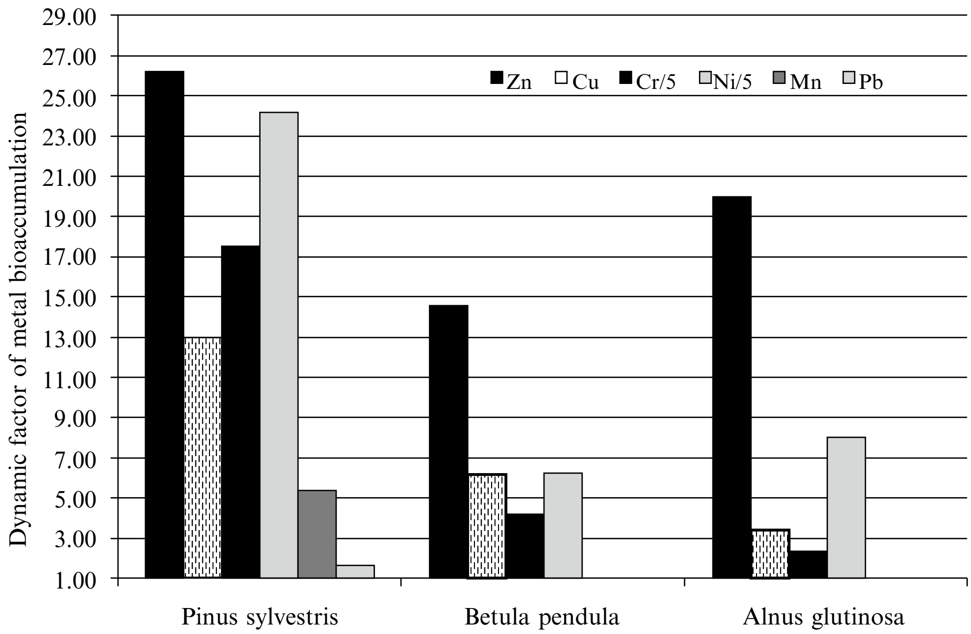

Fig. 2.1 Dynamic factors of metal bioaccumulation (BA_{dyn}). In the case of Cr and Ni, the factor values were reduced 5 times so that they could be compared to other metals

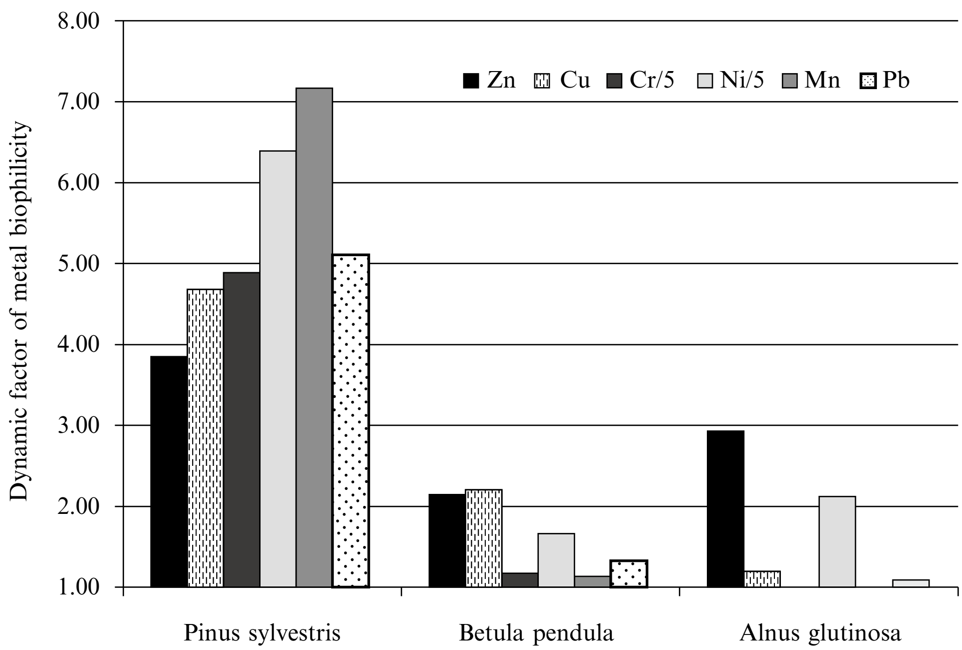

Fig. 2.2 Dynamic factors of metal biophilicity (BF_{dyn}). In the case of Cr and Ni, the factor values were reduced 5 times in order to make them comparable to other metals

BA_{dyn}, BF_{dyn}, and FR_{dyn}, which allow suggesting that on the one hand, the Scots pine accumulated higher amounts of metals and the accumulation was more intense when the soil contamination with metals increased. The higher accumulation common for the Scots pine was confirmed by Kovalevsky (1987) who studied the mechanisms of metal uptake by trees in non-contaminated areas. He stated that in respect of Pb and Cu, a non-barrier type of accumulation mechanism is common for the Scots pine. On the other hand, a more intense metal accumulation in the Scots pine can indicate its weakened protective functions and weaker immunity from environment's pollution, compared to the silver birch and the black alder. The weakened photosynthesis intensity of the Scots pine and its decreased immunity from the effect of contaminated air of its

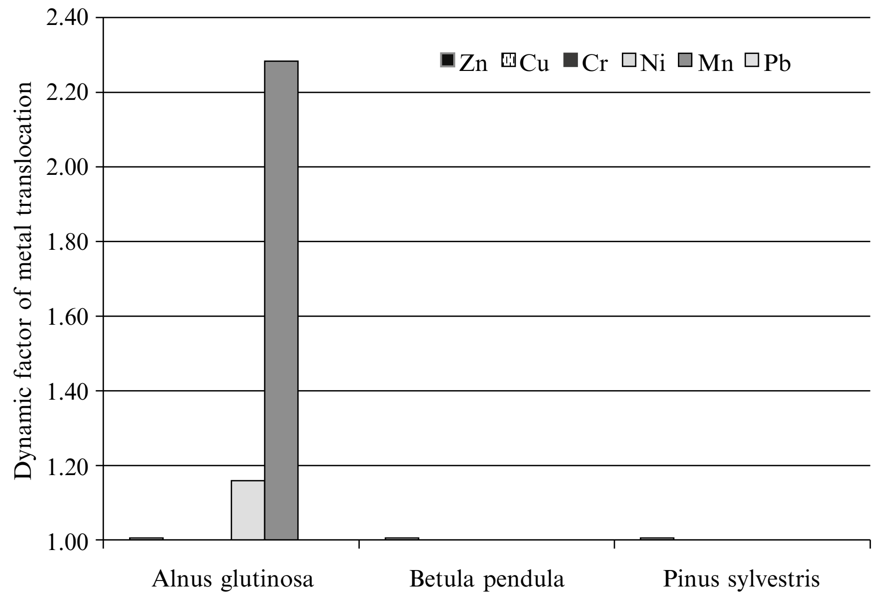

Fig. 2.3 Dynamic factors of metal translocation (TR_{dyn})

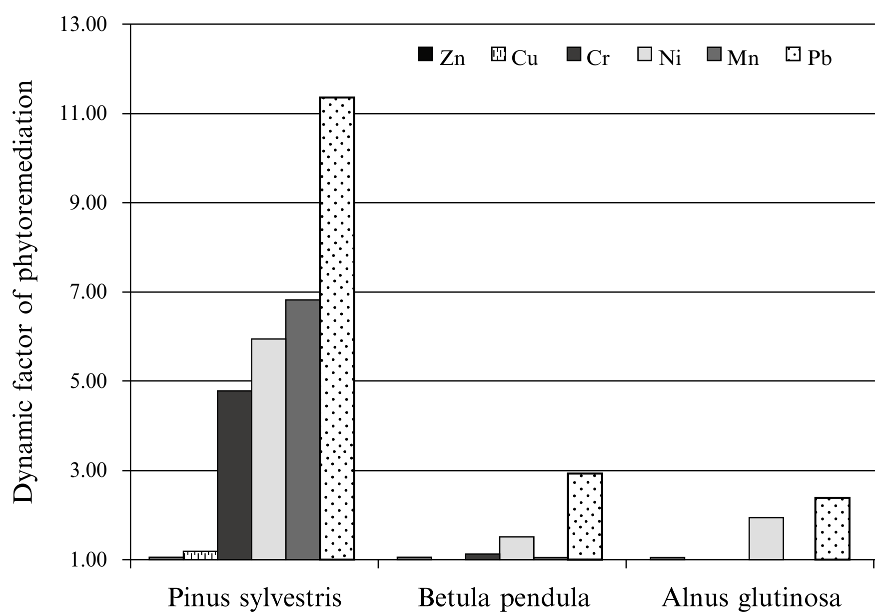

Fig. 2.4 Dynamic factors of phytoremediation (FR_{dyn})

environment, compared to the silver birch, has been established by Neverova and Jagodkina (2010). Thus, coniferous trees (as the example of the Scots pine showed) could be more affected by metal load than deciduous trees.

The TR_{dyn} value found in the black alder was higher (except for Pb with regard to the silver birch and Cr) than in other trees, which suggest that in a contaminated site the uptake of metals from the roots into the vegetative organs of the black alder was more intense. This does not oppose the fact that the black alder has a higher intensity of transpiration flow (2.59) than the silver birch (2.41) and the Scots pine (0.6) (where that of larch is equal to one) (according to L. Ivanov) (Milburn 1979; Zimmermann and Milburn 1982; Navasaitis 2008), which determines a faster transpiration flow uptake with metals dissolved in it, from the roots towards the vegetative organs.

2.3.3.2 Dynamic Factors Provide the Possibility to Compare the Influence of Soil Modification on the Participation of Chemical Elements (Metals as Well) in the Metabolism of Plants (Trees as Well)

Anthropogenic activity is also a stress to the vegetation, and heavy metals are classified as a stress factor (Kupčinskienė 2011); during the activity of which, the plants' metabolism alters, and other phenomena appear that are not common for the normal state of the plant. Soil modification with sewage sludge is also considered a stressor, and the participation of analyzed metals in the tree's metabolism is reflected in the dynamic factors of biophilicity and bioaccumulation, as well as in the altered sequence of metal biophilicity. Soil modification increased Ni and Cr biophilicity in the analyzed trees because compared to the tree's biophilicity sequence in the world's vegetation biomass—$Zn_{19.6}$ $Cu_{9.1}$ $Mn_{6.9}$ $Pb_{3.7}$ $Ni_{1.5}$ $Cr_{1.0}$ (Dobrovolsky 2008)—in our case Ni and Cr "moved" from the end to the beginning of the sequence.

Pinus sylvestris L.—$\mathbf{Ni_{31.94}}$ $\mathbf{Cr_{24.41}}$ $\mathbf{Mn_{7.16}}$ $\mathbf{Pb_{5.11}}$ $\mathbf{Cu_{4.67}}$ $\mathbf{Zn_{3.85}}$
Betula pendula—$\mathbf{Ni_{8.32}}$ $\mathbf{Cr_{5.88}}$ $\mathbf{Cu_{2.20}}$ $\mathbf{Zn_{2.14}}$ $\mathbf{Pb_{1.33}}$ $\mathbf{Mn_{1.13}}$
Alnus glutinosa—$\mathbf{Ni_{10.61}}$ $\mathbf{Cr_{3.27}}$ $\mathbf{Zn_{2.93}}$ $\mathbf{Cu_{1.19}}$ $\mathbf{Pb_{1.09}}$ $Mn_{0.84}$

Furthermore, in all the cases of analyzed trees, the BA_{dyn} and BF_{dyn} values of Ni and Cr were higher than one. These metals are known for their active participation in processes when a tree is affected by stressors. Jhee et al. (2005) found that Ni stimulates metabolism and enhances the permeability of cell walls, meanwhile Cr is an important stimulator of the lignification process that has been affected by stressors. Enlarged concentration of Ni and Cr was found in the Scots pine wood that has been affected by biotic factors (Baltrėnaitė and Butkus 2006).

2.3.3.3 Dynamic Factor of Phytoremediation Concretizes the Evaluation of Phytoremediation Efficiency

FR_{dyn} helps to decide which plant is more appropriate for phytoremediation. The results of our research revealed that the Scots pine was distinct for its higher metal accumulation and its elimination from the modified soil in the growth area: in 1 year it eliminated from 0.07–0.15 % (Cu, Pb, Ni, Zn) to 0.23–0.29 % (Cr, Mn) of the metals accumulated in a 40 cm soil surface layer. Meanwhile the silver birch rehabilitated the modified soil by 0.04–0.07 % (Cr, Cu, Pb and Ni) and 0.2–0.3 % (Zn, Mn), and the black alder by 0.01–0.04 % (Cr, Mn, Cu, Pb and Ni) and 0.1 % (Zn)%, compared to the control trees. Compared to the control site, the Scots pine accumulated more intensely and thus eliminated ($FR_{dyn} > 1$) Ni, Mn, Cu, Cr, and Pb from the modified soil; the silver birch Pb, Ni, and Cr; and the black alder Pb and Ni.

2.4 Conclusions

1. Bioindication and phytoremediation are applied aspects of the uptake of chemical elements from soil to plants. For bioindication and phytoremediation purposes, more and more graminaceous and ligneous plants are being evaluated, and more different media (soil–plant, plant–air) or the interfaces of different organs of the same organism (roots–vegetative organs) are analyzed. If the plant-based methods of improving environment observation gained a quantitative expression, they would receive more approval from the parties interested.
2. Dynamic indicators of bioaccumulation, biophilicity, translocation, and phytoremediation allow comparing changes in the processes of metal uptake in different plants (trees), by evaluating the geochemical features of the area of interest; they help to evaluate the influence of soil modification on the participation of chemical elements (metals as well) in the metabolism of plants (trees as well); they allow a quantitative evaluation of phytoremediation efficiency during a specific period of time. Dynamic factors integrate the internal (physiological) and external (ecological) factors.
3. In the case with trees, dynamic factors revealed several relevant tendencies: (1) *the dynamic factor of bioaccumulation* showed that after soil modification with sewage sludge, the metal uptake by trees became more intense in the following sequence: black alder < silver birch < Scots pine, while the Scots pine had the highest metal accumulation; (2) *the dynamic factor of biophilicity* highlighted the tendency that soil contamination may result in the metal biophilicity shift, e.g., the biophilicity of Ni and Cr increased significantly in respect of other metals within the sequence of generic biophilicity of the world vegetation; (3) by means of *the dynamic factor of translocation*, it was found that in the black alder the metal uptake from the roots to the vegetative organs increased more than in the silver birch or the Scots pine, due to the soil modification; (4) *the dynamic factor of phytoremediation* quantitatively estimated that the Scots pine, in respect of analyzed metals, is a better soil phytoremediator than the silver birch or the black alder.

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