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Developing a novel warning-informative system as a tool for environmental decision-making based on biomonitoring

Sorin Ştefănuţ[a], Anca Manole[a,*], Mihaela C. Ion[a], Marian Constantin[a], Cristian Banciu[a], Marilena Onete[a], Minodora Manu[a], Ioana Vicol[a], Mirela M. Moldoveanu[a], Sanda Maican[a], Ioana Cobzaru[a], Roxana G. Nicoară[a], Larisa I. Florescu[a], Elena D. Mogîldea[a], Dorina M. Purice[a], Claudia D. Nicolae[a], Rodica D. Catană[a], Gabriela Teodosiu[a], Cristina A. Dumitrache[a], Gabriel M. Maria[a], Ciprian Vâtcă[b], Melania Oanţă[b], Kinga Öllerer[a]

[a] *Institute of Biology Bucharest, Romanian Academy, 296 Splaiul Independenţei, 060031 Bucharest, P.O. Box 56–53, Romania*
[b] *I.M.U. Laboratories S.R.L., 202 Spl. Independenţei, 060021 Bucharest, Romania*

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ABSTRACT

Biomonitoring, i.e. using plant species for measuring pollution levels, has been previously explored in several locations using various protocols and organisms in the search for effective strategies and practices for monitoring and reducing the levels of pollution.

Here we present a tested and functional cost-effective method of using the foliar accumulation of tree species to develop a system for the long-term monitoring of airborne heavy metal bioaccumulation at a large, national scale. A total number of 1230 leaf samples have been collected during a vegetation season in 410 sampling locations scattered across Romania. Concentration levels were determined using an inductively coupled plasma mass spectrometer. Data from literature were used as reference values for the natural concentration of heavy metals in plants. Values exceeding these levels were considered as indicators of pollution, and used to define pollution thresholds. The maximum amounts measured in the collected samples were 152 $mg\,kg^{-1}$ dry weight for lead, 25.65 $mg\,kg^{-1}$ dry weight for cadmium, 65.51 $mg\,kg^{-1}$ dry weight for nickel and 4.81 $mg\,kg^{-1}$ dry weight for arsenic.

For analysing and communicating the findings, the BioMonRo software has been developed as a novel tool for warning-informing and decision-making. The software, now implemented by the Ministry of Environment for monitoring environmental quality, uses concentration data to build up national heavy metal pollution maps and can generate reports, which are automatically sent to various stakeholders. Based on our findings, we consider that tree species are efficient biomonitors, and similar methods could be successfully used in extensive biomonitoring programmes (national, regional or European), and for informing authorities.

1. Introduction

Being a hazard to human health, causing premature deaths and costly hospital admissions (Valavanidis et al., 2008; Bell, 2012), ambient airborne pollution has long been recognised as a systemic risk that should be addressed involving environmental, political, social and economic decisions and actions (Buekers et al., 2011). According to the one of the latest release of the European Environment Agency "air pollution remains the single largest environmental health hazard in Europe, resulting in a lower quality of life due to illnesses and an estimated 467 000 premature deaths per year" (European Environment Agency, 2016).

Despite the debate on which elements should be classified as heavy metals (Duffus, 2002), in the medical and environmental field this general term is used for metals and semimetals with potential human or environmental toxicity (Tchounwou et al., 2012).

* Corresponding author.
E-mail addresses: sorin.stefanut@ibiol.ro (S. Ştefănuţ), anca.manole@ibiol.ro (A. Manole), mihaela.ion@ibiol.ro (M.C. Ion), marian.constantin@ibiol.ro (M. Constantin), cristi.banciu@ibiol.ro (C. Banciu), marilena.onete@ibiol.ro (M. Onete), minodora.stanescu@ibiol.ro (M. Manu), ioana.vicol@ibiol.ro (I. Vicol), mirela.moldoveanu@ibiol.ro (M.M. Moldoveanu), sanda.maican@ibiol.ro (S. Maican), ioana.cobzaru@ibiol.ro (I. Cobzaru), roxana.ion@ibiol.ro (R.G. Nicoară), larisa.florescu@ibiol.ro (L.I. Florescu), daniela.sincu@ibiol.ro (E.D. Mogîldea), dorina.purice@ibiol.ro (D.M. Purice), claudia.bita@ibiol.ro (C.D. Nicolae), rodica.blindu@ibiol.ro (R.D. Catană), gabriela.teodosiu@ibiol.ro (G. Teodosiu), alina.coman@ibiol.ro (C.A. Dumitrache), gabriel.maria@ibiol.ro (G.M. Maria), ciprian.vatca@imu-lab.com (C. Vâtcă), melania.oanta@imu-lab.com (M. Oanţă), kinga.ollerer@ibiol.ro (K. Öllerer).

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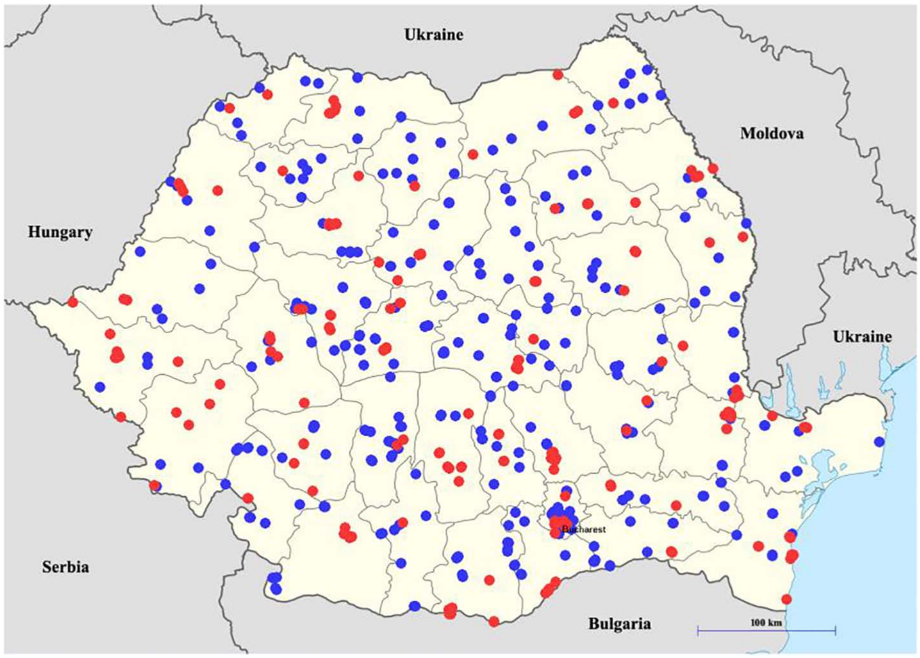

Fig. 1. The map of Romania showing the 410 sampling locations selected for biomonitoring. The 143 NAQMN stations are marked with red, while the 267 new locations are marked with blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In order to have a clear measure of airborne pollution and mitigate its threatening effects on environmental health, various methods have been developed for monitoring air quality, including automatic monitoring stations and also a relatively newer methodology called biomonitoring (Maslov, 2002). The latter uses biomonitors (microbial indicators, plant, animal or fungus species), which can provide data about the occurrence and quantity of a specific pollutant or of a broad range of pollutants and about the intensity of the exposure (Steinnes, 1977; Gerhardt, 2002; Markert et al., 2003; Bargagli, 2016). The first organisms used as bioindicators and biomonitors of air quality and atmospheric pollution were lichens, already in the mid-19th century (Nylander, 1866). Due to their increased sensibility against air quality variations, they are the first organisms to fade out from polluted areas (Riddell et al., 2011; Bargagli, 2016), being also ideal to reconstruct past atmospheric emissions (Wu et al., 2016). The biomonitoring of air pollution based on quantitative analysis of lichens, vascular plants and other groups of organisms has been explored ever since (Ferry et al., 1973; Markert et al., 1997; Conti and Cecchetti, 2001; Gerhardt, 2002; Markert et al., 2003). The use of biomonitors for quantifying airborne heavy metals pollution was proposed already in the 1960s (Bruin, 1990; Conti and Cecchetti, 2001), but it started to be used on broad scale only in the last decade (Wolterbeek, 2002), considering its advantages in assessing ecosystem health (Markert et al., 1999; Madejon et al., 2006).

Though there are many questions and discrepancies regarding the methodological aspects and comparability of findings for foliar bioaccumulation (reviewed for example by Tarricone et al. (2015) and Gillooly et al. (2016)), the advantages of biomonitoring are multiple, including the low-cost of sampling and the possibility to have a more integrated, ecosystemic approach (Markert et al., 1999), potentials which have been recognised even at high political levels (Klumpp et al., 2002).

Monitoring atmospheric contamination using deciduous tree leaves showed an increasing trend in the last decades, proving that tree leaves can be used as a low-cost proxy for intraurban air pollution (e.g. Klumpp et al., 2002; Aničić et al., 2011; Rucandio et al., 2011; Sawidis et al., 2011; Tomašević et al., 2011), but even at larger and more diverse spatial scales (e.g. Aboal et al., 2004; Madejón et al., 2004). These experiences highlighted there are still many uncertainties in developing a standardized protocol that enables the application of this technique as a tool to monitor air quality. Despite these aspects, the general conclusion of previous studies (reviewed by Tarricone et al. (2015) and Gillooly et al. (2016)) is that biomonitoring is a cost-effective method that corresponds to the growing need for low-cost and long-term pollution measures.

Considering the European and national legal framework requiring the assessment and mitigation of heavy metal pollution, the general tendency of developing “green technologies” and the results reported by previous biomonitoring initiatives, the main goal of our exploratory study was therefore to elaborate a methodology to biomonitor airborne heavy metals at a national level, using tree leaves, at first by gaining an insight into the element content of the leaves, and based on this to develop a support tool for the authorities to be used in the environmental decision-making process.

2. Materials and methods

2.1. Setting the sampling locations

In accordance with Law No. 104/2011 regarding ambient air quality, Romania has a National Air Quality Monitoring Network (NAQMN) with 143 stations for monitoring through direct measurements, distributed unevenly throughout the country. Since the aim of our study was to provide a complementary monitoring tool and also to detect hotspots of air pollution for Romania, we decided to build up a sampling network that would cover the entire country. Therefore, in order to provide a systematic coverage, we have designated 410 sampling locations, of which 143 were corresponding to those of NAQMN. The aim was to have a minimum of 8 sampling locations in each of the 41 counties. Some of the additional 267 sampling locations were in historically highly polluted areas (101 locations; e.g. Copșa Mică – one of the most polluted towns in Europe in the 1990s), while others in remote, unpolluted areas, such as Sites of Community Importance – SCI, included in the Natura 2000 network of protected areas (Evans, 2012; 47 locations), used as controls, the rest being represented by locations scattered across the country (Fig. 1).