Biological monitoring – the useful method for estimation of air and environment quality

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Abstract

Bioindication with different bioindicators (lichens, mosses, tree leaves and small mammals) has been used for thirty years (1975–2005) to estimate air pollution and environment contamination in Poland. Air contamination by heavy metals and sulphur dioxide in the Base Station of the Environmental Nature Monitoring System and in 23 Polish National Parks was estimated using lichen *Hypogymnia physodes* as a bioindicator. The impact of the Kraków conurbation and the contamination of forest ecosystems, using tree leaves and small mammals, were evaluated, respectively. Biological monitoring showed the changes of environment quality in Poland but also confirmed the presence of some areas still being contaminated. They are located in different parts of Poland also far from industrial sources.
Keywords: Poland, environment, biomonitoring, air pollution, heavy metals, sulphur dioxide, lichens, mosses, higher plants, small mammals.

1 Introduction

Chemical compounds which have caused organisms' and environmental stress were released into the environment as a result of human activities. The pollution originates mainly from industrial manufacturing and energy production, coal and oil combustion (industrial and residential), vehicular traffic and also small local sources. In the last few decades the main sources of pollution in the whole Europe have been increasing urbanisation and heavy traffic [1–3]. Biomonitoring – a very useful, sensitive and effective biological method to assess air pollution or to estimate contamination of natural environment – has been used for more

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than 50 years [4–7]. Biological monitoring is the measurement of the response of living organisms to changes in their environment [8]. According to other authors biological monitoring is the measurement, usually repeated, of concentrations of environmental contaminants in free-living organisms, or the measurements, either singly or in combination of changing of genetic, biochemical, physiological, behavioural and ecological parameters [9]. Generally lichens, plants and animals can be used as bioindicators. Several classifications of bioindicators are used. The simple one recognizes only two groups: monitors and indicators [10]. More complicated divide them for five groups: sentinels, detectors, exploiters, accumulators, bioassay organisms [11]. Biomonitoring can be used at national, regional and local scale but can also be used to compare the environmental contamination between various countries.

Poland used to be one of the most polluted countries in Eastern Europe – for many years taking one of the first places in sulphur dioxide, nitrogen oxide and dust emissions [12]. Country was heavily affected by gaseous and particulates emissions (including heavy metals) originating partly from our local sources, and partly from long distance transport, mainly from west direction. The situation has significantly improved during the last seventeen years, but still most of the natural environment is heavily contaminated. In 2004, Poland emitted 443 thousands tonnes of dust, 1241 thousand tonnes of sulphur dioxide, 804 thousand tonnes of nitrogen dioxide. Heavy metal emissions also decreased when compared with early nineties but in 2004 Poland emitted 1597 metric tonnes (t) of Zn, 600 t Pb, 46 t Cd, 20 t Hg, 54 t Cr, 249 t Ni, 389 t Cu [13]. At the present time the main sources of emissions are not the heavy industry but small towns, large conurbation, heavy traffic, and small local sources. In the most cities airborne metals, gaseous pollutant and organic compounds (e.g. PAHs) are not routinely monitored with fully or semi-automatic gauges commonly used in pollution monitoring programs, owing to elevated costs and technical difficulties. In this situation biological monitoring is the important method to study the quality and distribution of contaminants.

The aim of this paper is to show the role of biological monitoring in studying changes in contamination of natural environment in Poland during thirty years using different bioindicators.

2 Material and methods

Bioindicator samples (lichens, plants and animals) from natural environment were collected all over the Poland during thirty years (1975-2005). The investigated areas were located in different polluted parts of the country, around the heavy industry steelworks, metal smelters, coal and metal mining, busy road, small urban area and Cracow and Warsaw conurbations. Samples were also taken from different forest areas, national parks, and Base Stations of the Integrated Nature Monitoring System for Poland. Unwashed lichens, mosses, plant, leaves and animal tissues were dried to a constant weight (at 60-70˚C) and digested in a 4:1 nitric and perchloric acid. In all samples concentration of heavy metals: Cd, Pb, Cu, Zn, Fe, Ni, Cr, V (depends from the study) and S were determined. In case of metals, atomic absorption spectrophotometer flame or graphite furnace was used [6, 14], whereas sulphur content was determined using turbidimetric Butters-Chenry's method [15]. Simultaneously reference materials (SRM) were also analysed. Data are presented in $\mu g \cdot g^{-1}$ dry weight. Statistical analysis was carried to determine potential differences between the concentration of contaminants between sites and period of time.

3 Contamination of the environment in Poland

3.1 Lichens as monitors of air pollution

Lichens, the symbiotic association between fungus and alga, have been shown to be highly sensitive to gaseous air pollution, particularly to sulphur dioxide. They are very good indicator of this type of pollution. Lichens are generally insensitive to toxic effects of trace metals and can therefore be used as accumulator to estimate concentrations of these elements in the environment. They absorb substances for growth and survival through the exposed surface of the thallus. Epiphytic lichens growing on the tree stems and branches use them only as a substrate. Instead lichens get nutrients from rainwater and deposited dust. Along with the essential nutrients, they absorb many nonessential or harmful substances as well [16]. Lichens show the concentrations of metals and sulphur and organic compounds as a function of the amount of atmospheric deposition amount. Thus it makes them widely used in monitoring of air pollution [7, 17, 18]. They could be collected from natural environment or transplanted from clean area to the polluted sites [19, 20].

During 1997–2003 three different investigations (case studies) using epiphytic lichens *Hypogymnia physodes (L.)Nyl.* were carried out.

3.1.1 Contamination of Polish National Parks by heavy metals and SO_2

Samples of *Hypogymnia physodes* from natural environment were collected in July 1998 and 2003 from 23 Polish National Parks, Figure 1. The aim of this study was to estimate air pollution by heavy metals: Pb, Cd, Cu, Zn, Fe (Figure 2) and sulphur dioxide and to compare the contamination over period of 5 years [21]. Lichens from Ojcowski National Park situated in heavily industrialised region, had the highest concentration of all heavy metals. The lowest content of Cd, Pb and Zn were determined in Drawienski NP while the concentration of Cu and Fe were found in Białowieski NP. The highest concentrations of S were detected in lichens from Ujście Warty NP. As far as heavy metals, thirteen national parks were clean with very low pollution detected, nine represented moderately polluted areas and one was contaminated. In the case of SO_2, nine national parks were classified as clean; seven were recognized as moderately polluted, fifth as polluted and two were heavily polluted. Generally, national parks located in southern part of Poland were more contaminated by heavy metals than those in the north of the country.

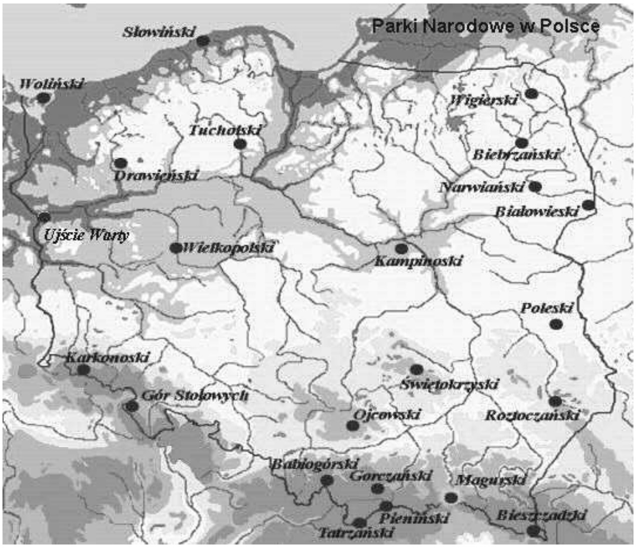

Figure 1: Localization of National Parks in Poland.

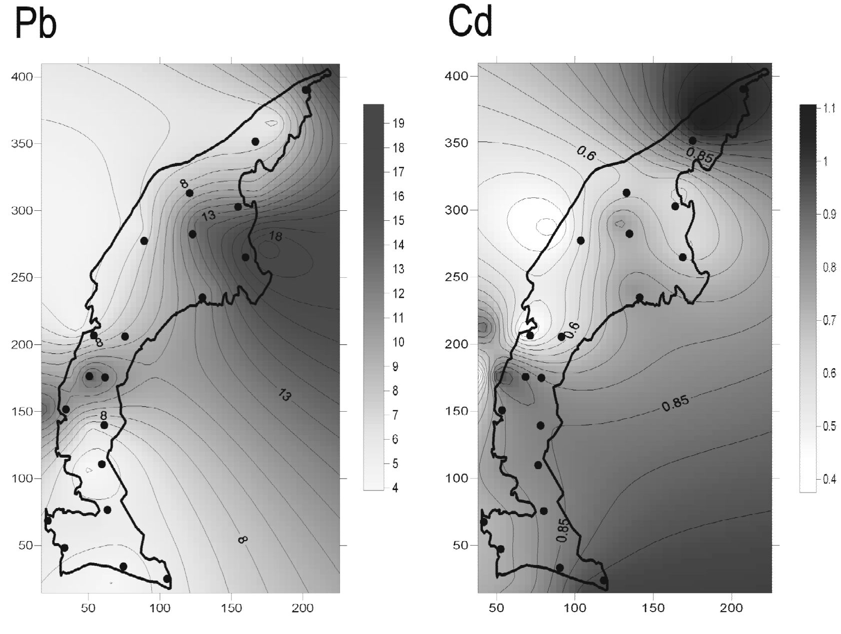

Figure 2: Lead and cadmium concentration (μg·g^{-1} d.w.) in the air of the Woliński National Park.

Contamination of sulphur dioxide is much more uniform across the country and reflect rather local sources of emissions and long distance transport than the main industrial sources. Comparison of environment condition after a five-year period showed that heavy metals and sulphur concentration was not much lower as was expected. Only in case of copper and iron the concentration was lower than five years ago. Zinc represents the same level. Lead concentration was slightly higher or remained on the same level. Cadmium concentration was higher than five years ago. Sulphur dioxide in Polish national parks has not decreased compared to 1998, as sulphur concentration is much higher than five years ago.

3.1.2 Air pollution in the Base Stations of the Integrated Nature Monitoring System

Air contamination by heavy metals and sulphur dioxide in Base Station of the Integrated Nature Monitoring System was estimated using *Hypogymnia physodes* as bioindicator [22]. In July 2001, lichen samples from natural environment were collected in all 7 Base Monitoring Stations (Szymbark, Św. Krzyż, Pożary, Storkowo, Koniczynka, Puszcza Borecka, Wigry) and determined for concentration of heavy metals (Cd, Pb, Cu, Zn, Fe) and S. The highest concentration of both: all investigated metals and sulphur were found in Koniczynka Base Station situated nearby Toruń agglomeration. Also high concentration of cadmium, lead, zinc, iron and sulphur were noticed in lichens collected in St. Krzyż and Szymbark Base Stations. Global pollution Index and Sulphur Index showed different air contamination of studied Base Stations. The results of the following study confirmed air contamination by heavy metals and sulphur dioxide in three of the investigated Base Stations (Koniczynka, Św. Krzyż, Szymbark). During winter season 2002/2003 and summer season of 2003 *Hypogymnia physodes* from clean area were transplanted to those three Base Stations to find out the reason and sources of pollution. The data for summer transplantation showed the lower accumulation of all heavy metals with exception for Cd in Szymbark and Cd, Pb and Fe in Św. Krzyż (see Figures 3 and 4). Significantly lower accumulation was found for sulphur in lichens from all investigated Base Stations (Figure 5). The sources of emissions which caused contamination are different in the case of these three areas.

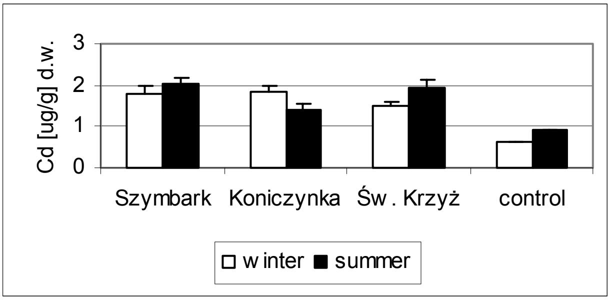

Figure 3: Cadmium content [$\mu g \cdot g^{-1}$d.w.] in lichens transplanted in the Base Stations.

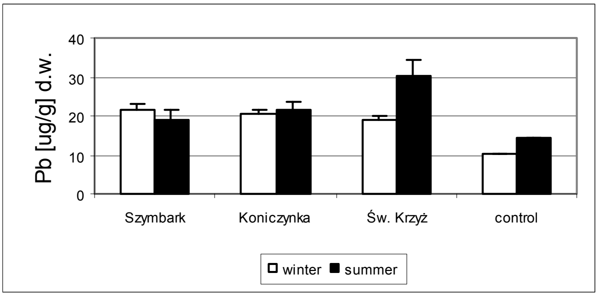

Figure 4: Lead content [$\mu g \cdot g^{-1}$d.w.] in lichens transplanted in the Base Stations.

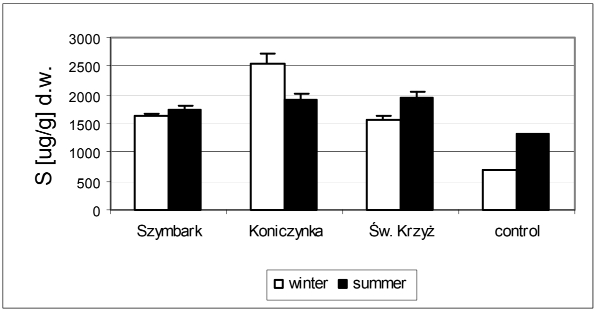

Figure 5: Sulphur content [$\mu g \cdot g^{-1}$d.w.] in lichens transplanted in the Base Stations.

3.2 Mosses as bioindicators of air pollution by heavy metals in Poland

Mosses accumulate large amount of heavy metals and therefore they are used as sensitive bioindicators of these contaminants in the environment [5, 8]. Mosses show the concentration of metals as the function of the amount of their concentration in air as they accumulate metals in the passive way [5, 23]. Another advantage that they are good bioindicator is that many moss species have a wide geographical distribution and are very common throughout the Europe. This is the reason that in EMAP two species of mosses *Pleurozium schreberi* and *Hylocomium splendens* were used as bioindicators of air pollution.

The first estimations of heavy metal contamination of the environment in Poland on a national scale, based on metal concentration in moss *Pleurozium schreberi* were conducted in 1975 in 12 Polish national parks [23]. The investigations were repeated in 1986, 1990 and 1995 [24–26].

In the project "Atmospheric Heavy Metal Deposition in Europe" the deposition of heavy metals in *Pleurozium schreberi* collected from 300 forest sites throughout Poland in 1990 and 1995 [26, 27]. Concentrations of seven heavy metals (Cd, Cr, Pb, Cu, Ni, Zn, Fe) in moss samples were analysed. The lower concentrations of all heavy metals were found in 1995 when compared with 1990 but despite these findings Poland is still the one of most contaminated areas in Europe [28].

3.3 Tree leaves as bioindicators of urban pollution

Tree leaves as the bioindicator of environment contamination were more frequently used in recent years, especially in urban areas [29, 30].

Seven forest sites that differed in their distance from Cracow conurbation and from busy roads were located along either southern or eastern transects and along the prevailing wind direction were selected. Five sites were located along southern transect (Bonarka located 3 km from the town centre, Rajsko 8 km, Mogilany located 14 km far from the city, Kornatka and Węglówka 26 km and 35 km respectively). Along the eastern transect only two sites: Koło (25 km from steelworks and 30 km from Cracow) and Ispina (30 and 35 km respectively) were located. Leaves from two tree species: hornbeam *(Carpinus betulus*) and oak (*Quercus robur)* were collected in the autumn for four consecutive years (1998-2001) from each forest sites [3]. High concentration of heavy metals (Cd, Pb, Cu, Zn, Fe) were detected in leaves of both species from eastern transect as the effect of steelworks emission, as well as in the sites from southern transect situated near the Cracow conurbation. Although the air pollution has generally declined in Małopolska district from the middle of nineties the metal concentration in tree leaves in 2001 remains at the same level than in the previous years [3].

3.4 Animals as monitors of environmental contamination

Animals, both invertebrates and vertebrates, have been used as bioindicators to assess environment contamination [9]. In many countries, small mammals have been used in assessment of heavy metal contaminations near smelters, mines, waste disposal sites, dumps, along the highways, [31, 32], see Figure 6. Small mammals are very useful monitors to estimate heavy metal concentration of forest, meadows or field ecosystems as they are closely adjusted to their environment.

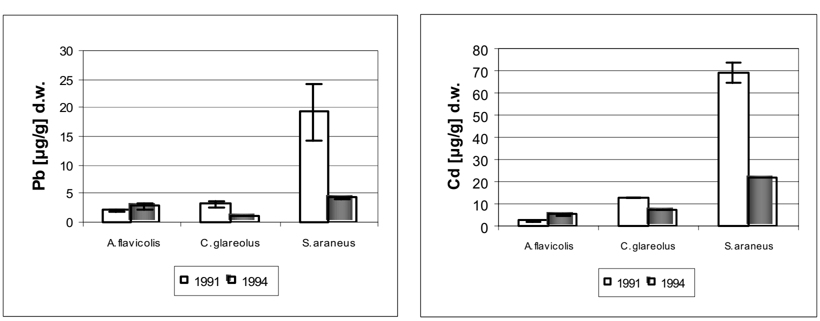

Figure 6: Lead and cadmium concentrations [$\mu g \cdot g^{-1}$d.w.] in the livers of small mammals from Olkusz Forest.

They are small enough and easy to catch. They have a territory of limited range and fairly short life span [9, 10, 31, 33]. In Poland, the levels of heavy metals in tissues and bodies of some rodents and insectivorous species were analyzed for almost thirty years. Concentrations of heavy metals in tissues and bodies of small mammals vary with the degree of contamination [33–37].

4 Conclusions

1. Air pollution and environment contamination in Polish national parks have not decreased much during last five years.
2. Air contamination in Base Stations of the Integrated Nature Monitoring System was at average levels when compared with the whole country, due to elevated cadmium concentration and high concentrations of lead and sulphur in some of the stations.
3. Mosses used as accumulators showed that Poland is still one of the most contaminated by heavy metals areas in Europe.
4. Tree leaves are very useful bioindicators of urban pollution which was confirmed in the Cracow conurbation.
5. Small mammals were good monitors for estimating changes of quality and contamination of the natural environment in Poland.
6. Biological monitoring showed the changes of environment quality in Poland during thirty years but also confirmed the presence of some areas still being contaminated. They are located in different parts of Poland also far from industrial sources.

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