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Use of plants for biomonitoring of airborne mercury in contaminated areas

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ABSTRACT

Biological methods provide a wide variety of possibilities to monitor mercury pollution in the environment. E.g., mosses and lichens give a good picture of the spatial distribution of mercury around pollution sources. On regional or global scale the accuracy is smaller and interpretation of the results more difficult. One reason for this is the long life-time and low reactivity of gaseous elemental mercury (Hg^0). At least temperature, light, concentration in air, speciation and biological factors affect the net deposition to or emission from vegetation. Different methods for estimating mercury fluxes between atmosphere and vegetation give different results. At contaminated sites the reaction types and fluxes most probably differ from those at uncontaminated sites. There are many pathways for mercury fluxes as well as physicochemical and biochemical reactions between different mercury species which makes it difficult to assess the fluxes in detail. Environmental conditions like temperature, light and humidity affect these fluxes. Compared to mechanical collectors biological monitors most probably give a more realistic picture of especially dry deposition but a lot of work has still to be done before we have accurate and reliable quantitative estimates of the deposition.

1. What is the problem?

There is a continuous need to monitor mercury and other pollutants in the environment. We need data from both contaminated and remote areas on local, regional and global scales. In addition, we want to know both spatial and temporal distribution as well as quantitative estimates of deposition. Monitoring can be focused on soil, water or air and it may be static (concentrations and pools) or dynamic (fluxes). Biomonitoring may also provide data for environmental risk assessment by measuring or predicting metal concentrations in the environment and possibly by estimating stress to man and nature due to metal exposure. Also animals like earthworms and insects have successfully been used for biomonitoring purposes but they are not considered in this review.

Many heavy metals are considered environmentally dangerous as they are toxic, persistent and/or bioaccumulative. Mercury is e.g., in the 1998 Aarhus Protocol on Heavy Metals considered particularly harmful along with cadmium and lead. This protocol is based on the 1979 Geneva convention on long-range transboundary air pollution (CLRTAP). The EU-countries have committed to substantially reduce their emissions of mercury and other harmful metals. One part of this work is the surveys of heavy metals in mosses, which started in Sweden and have later been carried out every 5 years in at least 21 countries since 1990 (Harmens and Norris, 2008). The mosses in these surveys are sampled and analyzed according to joint instructions mostly in forested areas, in order to assess regional and Europe-wide metal distribution and deposition. The monitoring programme is connected to the European Monitoring and Evaluation Programme (EMEP). The main goals of the moss surveys are to provide spatial information on the distribution of heavy metals, identify main polluted areas, and monitor temporal trends.

There are many different methods for monitoring: different technical collectors and analytical equipment, biological and integrated sampling, permanent and occasional, cheap and expensive methods. These are not necessarily compatible— they may be based on different phenomena and measure different aspects of the same thing. Several attempts have been made to evaluate the reliability and comparability of technical and biological methods (e.g., Steinnes, 1995; Berg and Steinnes, 1997; Amblard-Gross et al., 2002; Aboal et al., 2010) but there are still a lot of inaccuracies and uncertainties. Especially the use of bioindicators for quantifying the deposition rate is an urgent challenge.

In typical cases our aim can be to:

- study the spatial distribution of mercury,
- identify pollution sources or hot spots,
- quantitatively estimate mercury fluxes (dry, wet or total),
- estimate temporal trends of concentrations and/or fluxes and
- establish a dense sampling network at low costs.

In order to promote the use of biological indicators it is important to evaluate different methods. We have to consider

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the purposes and needs for monitoring: qualitative, semiquantitative or quantitative estimates? Spatial and/or temporal distribution? What degree of accuracy and reliability? In this critical discussion paper I concentrate on the use of plants as biological indicators of atmospheric mercury. What are the possibilities to monitor airborne mercury pollution in contaminated areas by using different biological methods? What are these methods based upon and how reliable are they? This review aims at describing and comparing different biological methods for monitoring airborne mercury fluxes with special emphasis on contaminated sites. Advantages, limitations and reliability will be considered.

Definitions:

- **Bioindication:** the response of a living organism to changes in the environment.
- **Bioindicator:** a biological organism used to indicate the state of the environment, e.g., the degree of metal pollution.
- **Biomonitor:** a more or less regularly repeated measuring of the state of the environment using bioindicator(s).
- **Transplant:** a bioindicator (e.g., moss or lichen) transferred usually from an unpolluted site to a polluted one.

2. Why use biological indicators?

Biological monitoring can be defined as "measurement of the response of living organisms to changes in their environment" (Burton, 1986). Living organisms are normally best for monitoring purposes but in transplant methods also dead or dying tissues may be used. In terrestrial environments many species or groups of species may be used for monitoring purposes. They can be used for soil, air and water environments. E.g., lichens, mosses, vascular plants and mushrooms have successfully served as passive biomonitors for airborne metal pollution. When the temporal aspect is important it is possible to use transplants, e.g., moss bags which are exposed for a certain period of time. All these biomonitoring tools give accurate information on the spatial distribution of mercury around a pollution source.

Mercury circulation between atmosphere, vegetation and soil includes many different pathways (Fig. 1) as well as physical, chemical and biological processes. An essential advantage with biological indicators is the structure of the surface which is completely different from that of technical collectors containing surfaces of glass, teflon, stainless steel etc. Some plant surfaces like conifer needles are thick and smooth but often biological surfaces consist of complicated structures including hair and stomata. These structures often trap particles, liquids and even gases effectively although our knowledge about the mechanisms and chemistry of this binding is limited. In addition, the effective surface may be considerably larger than a smooth "technical" surface. In most areas majority of the dry and wet deposition will occur on vegetation. As we use the same methods (technical or biological) in different areas we know too little about the differences in actual deposition between e.g., urban areas, open fields, forests and lakes.

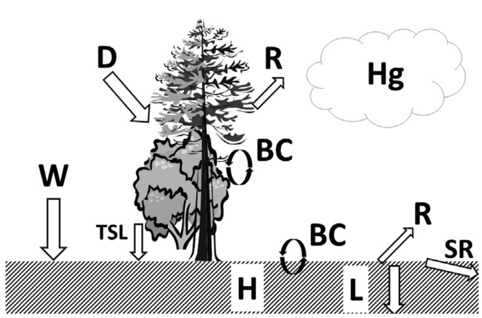

Fig. 1. Schematic presentation of mercury fluxes between atmosphere, vegetation and soil: mercury in the atmosphere (Hg) may reach the soil and its humic matter (H) via wet deposition (W) or dry deposition (D). From the vegetation mercury may move down by troughfall, stemfall or litterfall (TSL) or be evaporated or re-emitted (R) to the atmosphere. From the soil surface mercury may leach downwards (L) or flow to surface waters via surface runoff (SR). In both soil and vegetation mercury may be involved in biological circulation (BC) including bacteria, fungi and invertebrates.

The most important advantages, disadvantages and problems connected with the use of biological monitoring can be summarized as follows:

Advantages

- the methods are useful for short and long periods,
- they indicate changes in the ecosystem,
- the biological methods are often easy to use and cheap,
- some methods offer possibilities for at least semiquantitative estimates of deposition.

Disadvantages

- The methods give no exact data for concentrations in air, water or soil, nor any exact figures for deposition,
- there are many different methods, only a few are standardized,
- bioindicators may be absent in polluted areas,
- there are not suitable indicators for all environmental changes,
- natural ecosystems are complex and may include complicated interactions between species,
- normally, no speciation between different forms of mercury can be measured.

Problems and challenges

- the exchange of mercury between vegetation and atmosphere is bidirectional,
- different mercury species (e.g., Hg^0 and Hg^{2+}) behave differently,
- indicator species are not necessarily common in all areas,
- species may adopt to changes caused by pollutants,
- the relation between exposure and uptake or re-emission of mercury is possibly not linear,
- the knowledge concerning genetic variation in the species used is insufficient.

3. Commonly used biomonitoring methods

3.1. Mosses and epiphytic lichens

Mosses have been successfully used for decades for monitoring of heavy metal deposition (e.g., Tyler, 1970; Rühling and Tyler, 1971; Steinnes, 1977, 1985; Lodenius and Tulisalo, 1984; Berg and Steinnes, 1997; Harmens and Norris, 2008). The weak or absent cuticle in combination with very thin leaves enables easy exchange between atmosphere and cell walls. Epiphytic lichens have proved effective mercury monitors at contaminated sites both in situ and after transplantation (Horvat et al., 2000, Ljubič-Mlakar et al., 2011).

At local scale we have many examples of successful biomonitoring of mercury from pollution sources but due to occurrence in gaseous form, long-distance transport and long residence time in atmosphere mercury – especially Hg^0 – has been characterized as a global pollutant without distinct spatial deposition patterns at regional scale (e.g., Steinnes et al., 2003; Ryaboshapko et al., 2007;