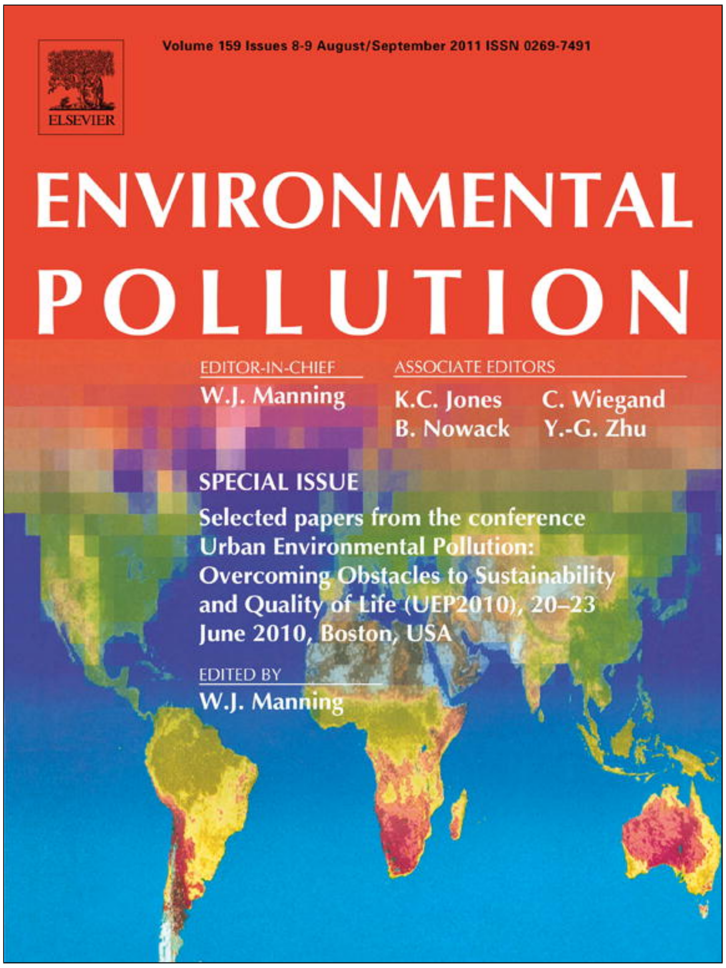
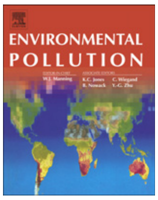

Volume 159 Issues 8-9 August/September 2011 ISSN 0269-7491
ELSEVIER
ENVIRONMENTAL
POLLUTION
EDITOR-IN-CHIEF
W.J. Manning
ASSOCIATE EDITORS
K.C. Jones
C. Wiegand
B. Nowack
Y.-G. Zhu
SPECIAL ISSUE
Selected papers from the conference Urban Environmental Pollution: Overcoming Obstacles to Sustainability and Quality of Life (UEP2010), 20–23 June 2010, Boston, USA
EDITED BY
W.J. Manning

Environmental Pollution 159 (2011) 1991–1995

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol



Bioindication of atmospheric trace metals – With special references to megacities

Bernd Markert [a,*], Simone Wuenschmann [a], Stefan Fraenzle [b], Ana Maria Graciana Figueiredo [c], Andreza P. Ribeiro [c], Meie Wang [d]

[a] Fliederweg 17, D-49733 Haren/Erika, Germany
[b] International Graduate School Zittau, D-02763 Zittau, Germany
[c] Instituto de Pesquisas Energeticas e Nucleares, IPEN-CNEN/SP, Av. Prof. Linea Prestes 2242, CEP 05508-090, São Paulo, Brazil
[d] State Key Laboratory of Urban and Regional Ecology, Research Centre for Eco-environmental Sciences, Beijing 110016, China

ARTICLE INFO

Article history:
Received 7 September 2010
Received in revised form
16 January 2011
Accepted 4 February 2011

Keywords:
Chemical pollution
Health care
Multi-Markered-Bioindication-Concept (MMBC)
Atmospheric deposition
São Paulo

ABSTRACT

After considering the particular problems of atmospheric pollution in megacities, i.e. agglomerations larger than 5 mio. inhabitants, with urbanization of World's population going on steadily, possibilities of active biomonitoring by means of green plants are discussed. Based on specific definitions of active and passive bioindication the chances of monitoring heavy metals in Sao Paulo megacity were demonstrated (first results published before). This is to show that there is need for increased use of bioindication to tackle the particular problems of megacities concerning environmental "health", the data to be processed according to the Multi-Markered-Bioindication-Concept (MMBC). Comparison to other work shows this approach to be reasonable.

1. Introduction

Numbers of towns[1] steadily increase globally. Some 200 years ago (in 1800) just 25% of German population lived in cities, as opposed to 75% in rural environments, while in 2005 the population share of German towns had increased to 85%. Similar developments are observed in all industrialized countries: as of 2005, the corresponding shares of urban populations were 61% in Eire, a stunning 97% in Belgium, 77% in France, 90% in UK, 66% in Japan, 73% in Russia and 81% in USA. The increase in number and average population was largest in megacities (megacities are not subject to an unequivocal definition but usually the minimum is taken to be 3 mio. inhabitants [about the size of Rome, Chicago, Kiev, Montreal, Berlin, or Sydney], but sometimes higher limits of five, eight, or even ten mio. inhabitants are taken). Anyway, we will count Mexico City (23 millions), São Paulo (20 millions), Beijing (17 millions), Buenos Aires (15 millions) Rio de Janeiro (11 millions), and Santiago de Chile (5 millions) among the megacities.

Atmospheric burdens are enormous in megacities. If pregnant women are exposed to CO, the fetus will be harmed. Likewise, experts agree that car exhaust gases strongly damage children's health, including effects on behaviour and psycho-social development (Chelala, 2010).

In Mexico City, which is notorious for air pollution (at a total of >4.5 mio tons/a of hazardous substance inputs), also children are exposed, with authorities keeping them from attending school if the extent of pollution in town is particularly high. Mexico City is not an exception; about the same holds for almost all large cities in the Western hemisphere but also in Chinese cities, Lagos in Nigeria, or in Tehran the capital of Iran and others.

Due to high levels of atmospheric pollutants, inhabitants of Santiago de Chile struggle with chronical respiratory diseases. There, pollutants stay airborne longer than elsewhere and hence

---

* Corresponding author.

E-mail address: markert@schlundmail.de (B. Markert).

[1] Terms "town" and "city" are not given a consistent legal definition by administration rules, at least so far as number of inhabitants is concerned (in Central Europe, there are rather many "towns" <1000 inhabitants, while in developing countries there may be settlements of >>50,000 lacking both the legal status of "town" and corresponding infrastructures). For our purposes, a town rather is a centralized settlement with clear-cut edges towards the (rural, desert etc.) environment which maintains an administrative and support infrastructure of its own and is connected to traffic by intersecting traffic ways within. Given these structural, rather than administrative features, almost every central settlement can be considered a town.

0269-7491/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envpol.2011.02.009

accumulate due to topographical and climate peculiarities, with Santiago “sandwiched” in between the (Pacific) ocean and nearby Andean mountains.

Neither, Buenos Aires will escape these problems. Due to both pollutant and noise emissions, it became one of the most polluted cities in the World (Chelala, 2010).

In terms of extent and hazards, air pollutions does compete against other forms of pollution coming from waste materials, including pesticide residues and toxic industrial wastes. In Santiago de Chile, some 300 million cubic meters of untreated sewage water are estimated to be poured into the two rivers and the main watering (!) channel of this metropolis (Chelala, 2010).

All the environmental compartments air, water, soil and the biocoenoses associated with them are considerably influenced by a larger number of both biotic and abiotic factors (Ellenberg et al., 1986; WHO, 1996; Haber, 2009; Zhu and Jones, 2010). Owing to an increasing extent of anthropogenic activities, the environment is especially influenced by chemical pollutants (Lee and Tallis, 1973; Adriano, 1992; Loppi and Bonini, 2000; Freitas et al., 2006; Franca et al., 2007). This diverse group of potentially hazardous substances contains a larger number of organic compounds and chemical elements as well as “heavy” metals (e.g. mercury and tin), so-called semi-metals (e.g., arsenic and antimony), and organo-metal compounds (like tributyl tin). Once they get accumulated in soil, ground water or organisms, drawbacks for certain members of a trophic chain may become unpredictable yet grave (Markert et al., 2003; Marcovecchio and Ferrer, 2005; Rauch, 2010; Wolterbeek, 2002; Wolterbeek et al., 2003, 2010; Zhu and Jones, 2010).

Already ancient high cultures used metals to an extent emissions from which can be detected globally by corresponding depositions in e.g. Greenlandic ice cores. During the last 150 years, however, anthropogenic emissions got that large that negative effects on man and his environment were no longer restricted to the regional surroundings of emission sites (Markert, 1994; Fraenzle and Markert, 2007). Accumulation being a slow, unconspicious process which, however causes a likewise slow damage to living organisms requires a meticulous and constant surveillance of deposition of chemical elements (and likewise organic compounds, also) and of their impacts to living nature (Baker and Brooks, 1989; Wuenschmann et al., 2008). Emissions into the atmosphere are often monitored by means of (technical) deposition collectors whereas in aquatic monitoring a – however not continuous but intermittent – sampling of water samples is employed. Additionally different sampling procedures and technical instrumental analysis can be found for sediment or soil samples (Djingova and Kuleff, 2000; Namiesnik and Szefer, 2009).

However, there is an elegant though indirect method to obtain data on existence, distribution and effects of pollutants, namely, bioindication respectively (Aksoy and Ozturk, 1997; Bargagli, 1998; Pignata et al., 2002; Markert et al., 2003; Hempel et al., 2008; Ozturk et al., 2008; Pla et al., 2009; Wolterbeek et al., 2010). Both biological methods make use of the capacity of organisms to signify presence of pollutants over either short or longer periods of time. Markert et al. (1997) gave an exact and now generally valid definition to discern among bioindication. Bioindicators are organisms or communities of organisms whose content of certain elements or chemical compounds and/or whose morphological, histological or cellular structure, metabolic-biochemical processes, behaviour or population structure(s), including changes in these parameters, supply information on the quality of the environment or the nature of environment changes.

We speak of active bioindication when organisms bred in laboratories (or grown in specific mostly unpolluted regions) are exposed in a harmonized (better standardized) form in the field for a defined period of time. In the following one example of active bioindication will be described with the exposition of *Tillandsia usneoides L.* in São Paulo. At the end of this exposure time the reactions provoked are recorded or the xenobiotics taken up by the organism are analyzed. In the case of passive bioindication, organisms already naturally occurring in the ecosystem are examined for their reactions. Other important definitions used in bioindication/biomonitoring as reaction/effect/impact or accumulation indicators, or biomarkers (mainly used in highly standardized lab experiments by ecotoxicologists), etc., can be found in Markert et al. (1997, 2003).

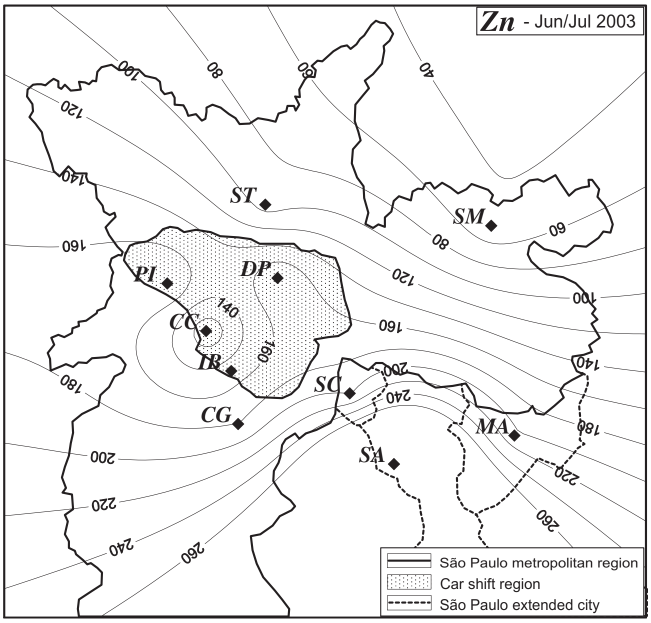


Fig. 1. Distribution map of Zn in the metropolitan region of São Paulo (June/July 2003). Stations: ST = Santana; IB = Ibirapuera; CG = Congonhas; SA = Santo Andre; SC = Sao Caetano; MA = Maua; CC = Cerqueira Cesar; PI = Pinheiros; DP = Parque D. Pedro; SM = Sao Miguel (Figueiredo et al., 2007).

Because bioindicators do integrate environmental burdens (by chemicals) over time of experiment at their sites, (very) short-term variations are cancelled out. As compared to “conventional” means of measuring emissions, doing bioindication takes much less expenditures in both personnel and apparatus than e.g. running a deposition sampler. Hence bioindicators can be employed throughout large areas provided the organisms are sufficiently far-spread and abundant, enabling investigations which cover entire countries or even continents which could be done otherwise only if accepting very high demands of work and money. Using one or several (different) organismic species for purposes of estimating environmental burdens brings about yet another advantage: beyond statements on the very organism which is embedded in some ecological niche within an ecosystem, hence analytical data obtained on it can be integrated into a more comprehensive biological system. Thus beyond the very bioindicator ecologically relevant statements are possible on larger parts of the biocoenosis due to the biotic interactions which interconnect them, unlike when using direct physico-chemical methods.

The aim of this study is, to demonstrate that bioindication methods can be used effectively in so called megacities. Here especially active bioindication methods are of importance, because the bioindicational organisms are not simply available in the megacity, they have to being exposed for a time.

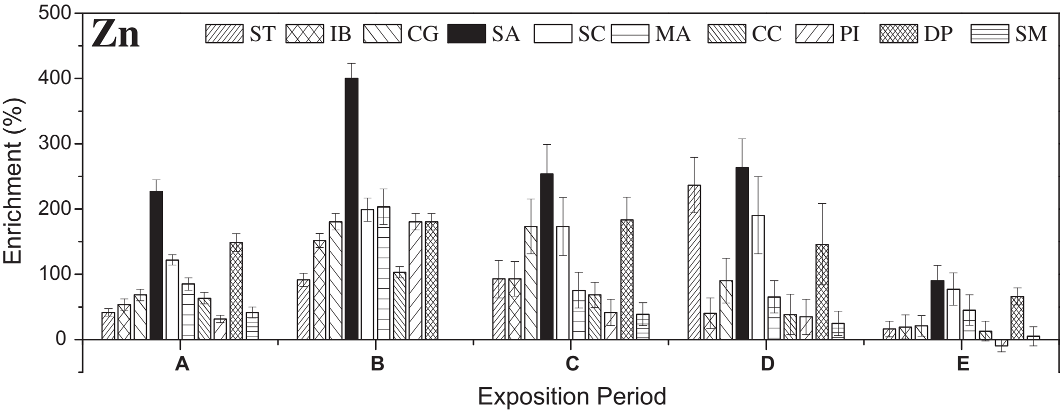


Fig. 2. Enrichment of the element Zn (%) in *Tillandsia usnoides* to the exposure period and exposure site (Figueiredo et al., 2007). Exposure period: A = April–May/2000; B = June–July/2002; C = Nov./2002–Jan./2003; D = Feb.–April/2003; E = April–May/2003. Stations: ST = Santana; IB = Ibirapuera; CG = Congonhas; SA = Santo Andre; SC = Sao Caetano; MA = Maua; CC = Cerqueira Cesar; PI = Pinheiros; DP = Parque D. Pedro; SM = Sao Miguel (Figueiredo et al., 2007).

2. Transferring the method of bioindication to megacities

In the past 10 years more on more activities were undertaken to transfer the bioindication method into the pollution control observations of so called megacities. In the following we would like to report on results of São Paulo (Figueiredo et al., 2001, 2007), the biggest megacity of Brazil having around 20 million inhabitants. For this reason *Tillandsia usneoides* L., an epiphytic bromeliad plant, was chosen, because this plant is able to absorb water and nutrients directly from the air (Vutchkov, 2001; Vianna et al., 2010). Five consecutive transplantation experiments (8 weeks each) were performed in 10 sites of the city, submitted to different sources of air pollution (industrial, vehicular), using plants collected from an unpolluted area. After exposure, trace metals were analyzed in the plant by instrumental neutron activation analysis. Distribution maps (Fig. 1) were drawn, which demonstrate that traffic related

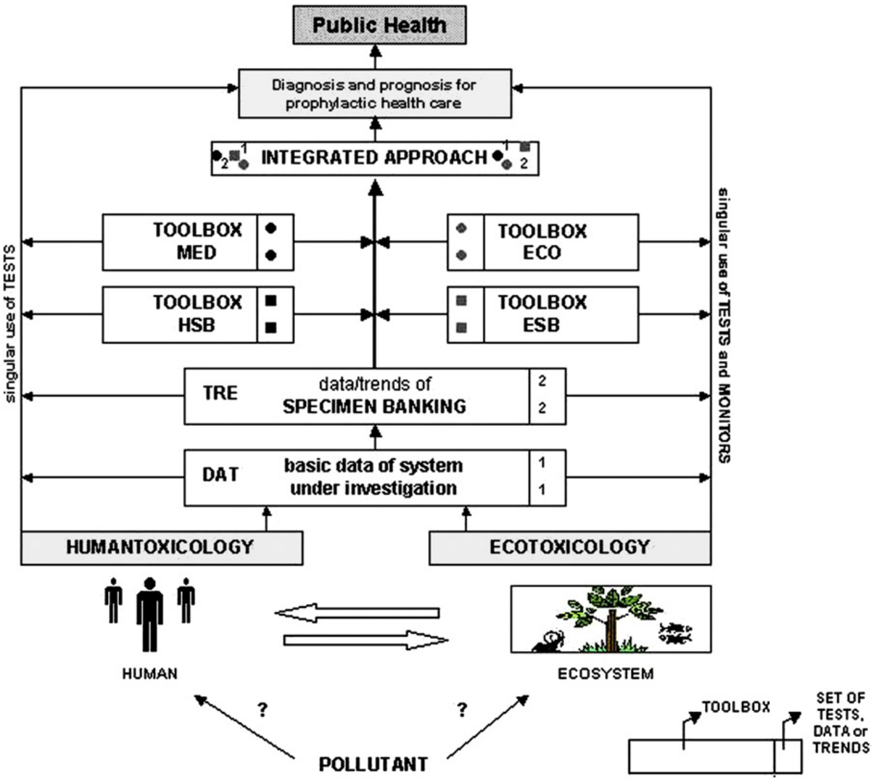


Fig. 3. MMBC: Multi-Markered-Bioindication-Concept, an integrative approach on human health care which draws upon a multidisciplinary input organized along several integrated and functional “windows”. MMBC is one way how bioindicative toolboxes may be organized in a hierarchical framework for purposes of human and ecotoxicology. In toolboxes MED and ECO, respectively, there are single sets of tests for functional combination in order to obtain an integrated approach towards some specified scientific problem. Toolboxes HSB (Human Specimen Banking) and ESB (environmental specimen banking) derive from years of research using sample banks for both human and environmental toxicology; thus they can supplement MED and ECO by important information on toxicological and ecotoxicological features of environmental chemicals. This integrated approach is not only to link all the results but to corroborate them by data already available from (eco-)systems research, toxicology, environmental monitoring and specimen banks. Toolboxes TRE and DAT provide parameters required to accomplish this (Markert et al., 2003).

elements such as Zn (and Ba, not given in Fig. 1) presented high concentrations in exposure sites near to heavy traffic avenues (cars, buses and trucks) and may associated to vehicular sources (Ribeiro et al., submitted for publication).

For Zn (and Co) the highest contents were related to industrial zones and can be associated to the presence of anthropogenic emission sources. The rare earth elements, Fe and Rb probably have soil particles as main source.

In Fig. 2 the enrichment in concentration for Zn in *T. usneoides* exposed in the monitoring sites in relation to the concentrations measured in plants from the control site during the monitoring period is represented. In many cases, the highest increase in concentration occurred in winter time (Exposure B: June–July/2002), in opposition of a period of lower enrichment in relation to the control sample observed in summer (Exposure C: Nov/2002–Jan/2003). These seasonal changes in relation to a summer/winter oscillation is already well know to other epiphytic plants, as mosses (Markert and Weckert, 1993).

Highly promising "starter projects", to introduce bioindicative methods into other megacities were already done f.e. in Beijing by Wang et al., 2010, 2011. In these investigations special interests were focused on the pollution status of soils.

3. Discussion – construction of a setup for preventive healthcare and conclusions/outlook

With bioindicative methods being used for monitoring release, distribution, effects and control of pollutants an integrative approach towards monitoring on larger spatial scales – as well as including quite diverse sets and sources of information – is suggested (Multi-Markered-Bioindication-Concept, MMBC), meant to be eventually used for preventive healthcare on the scale of counties (Fig. 3).

Fig. 3 represents only one proposal of a complete dynamics environmental monitoring system supported by bioindication to integrate human and ecotoxicological approaches. It can be recombine its measurements parameters according to the particular system to be monitored or the scientific frame of reference. Therefore it seems to have good chances to being transferred into use for the pollution control observation in megacities.

To come closer to a prophylactic healthcare system (independent of in megacities or in smaller cities or rural areas) we should come to a more integrated understanding on an international, interdisciplinary and intercultural level (Simeonow and Simeonova, 2009). For overcoming existing gaps during the international education of pupils and students and for getting common research projects financially sponsored, the public must be convinced by day by day activities (Markert et al., 2008; Trapp and Rein, 2009; Davies and Stephens, 2010).

Acknowledgements

We would strongly like to thanking all international colleagues working in different fields assisting us in understanding problematic issues in use of bioindicative and biomonitoring methods for dealing with the status of our environment. Without their strong advices, discussions and assistance during the past 25 years, a development in the form described in this paper would never been possibly.

For sure we are thankful to Prof. Bill Manning and the local organizers of the Urban Environmental Pollution (UEP) conference in Boston for opening the first author the possibility to giving his thoughts to an international audience, and Elsevier, especially to Gert-Jan Geraeds and an independent reviewing committee, to accepting this talk as an invited paper for Environmental Pollution. Kay Russell and her team of Elsevier is deeply thanked for the perfect logistically organisation during the exciting days in Boston.

References

Adriano, D.C. (Ed.), 1992. Biogeochemistry of Trace Metals. Lewis, Boca Raton.

Aksoy, A., Ozturk, M., 1997. Nerium oleander L. as a biomonitor of lead and other heavy metals pollution in mediterranean environments. Sci. Total Environ. 205, 145–150.

Baker, A.J.M., Brooks, R.R., 1989. Terrestrial higher plants which hyperaccumulate metallic elements – a review of their distribution, ecology and phytochemistry. Biorecovery 1, 86–126.

Bargagli, R. (Ed.), 1998. Trace Elements in Terrestrial Plants – An Ecophysiological Approach in Biomonitoring and Biorecovery. Springer, Heidelberg.

Chelala, C., 2010. Rapid Urbanization has an Impact on Health. The Epoch Times. www.theepochtimes.com/n2/content/view/27602/.

Davies, L., Stephens, G., 2010. A community-driven environmental research program. Invited talk at the UEP conference, June 20–23, 2010, Boston.

Djingova, R., Kuleff, I., 2000. Instrumental techniques for trace analysis. In: Markert, B., Friese, K. (Eds.), Trace Elements, Their Distribution and Effects in the Environment. Elsevier, Amsterdam, pp. 137–185.

Ellenberg, H., Mayer, R., Schauermann, J., 1986. Ökosystemforschung. Ergebnisse des Solling Projektes. Ulmer, Stuttgart.

Figueiredo, A.M.G., Saiki, M., Ticianelli, R.N., Domingos, M., Alves, E.S., Markert, B., 2001. Determination of trace elements in Tillandsia usneoides by neutron activation analysis for environmental biomoitoring. J. Radioanal. Nucl. Chem. 249, 391–395.

Figueiredo, A.M.G., Nogueiro, C.A., Saiki, M., Milian, F.M., Domingos, N., 2007. Assessment of atmospheric metallic pollution in the metropolitan region of São Paulo, Brazil, employing Tillandsia usneoides L. as biomonitor. Environ. Pollut. 145, 279–292.

Fraenzle, S., Markert, B., 2007. Metals in biomass: from the biological system of elements to reasons of fractionation and element use. Environ. Sci. Pollut. Res. 6, 404–413.

França, E.J., De Nadai Fernandes, E.A., Bacchi, M.A., Tagliaferro, F.S., Saiki, M., 2007. Soil-leaf transfer of chemical elements for the Atlantic Forest. Radioanalyt. Nucl. Chem. 271 (2), 405–411.

Freitas, M.C., Pacheco, A.M.G., Vieira, B.J., Rodrigues, A.F., 2006. Neutron activation analysis of atmospheric biomonitors from the Azores: a comparative study of lower and higher plants. Radioanalyt. Nucl. Chem. 270, 21–27.

Haber, W., 2009. Nachhaltige Entwicklung unter human-ökologischen Perspektiven im globalen Wandel. Erste Hans Carl von Carlowitz-Vorlesung des Rats für Nachhaltige Entwicklung anlässlich seiner 9. Jahreskonferenz am 23. November 2009 in Berlin.

Hempel, M., Botte, S.E., Negrin, V.L., Nedda Chiarello, M., Marcovecchio, J.E., 2008. The role of the smooth cordgrass Spartina alterniflora and associated sediments in the heavy metal biogeochemical cycle within Bahia Blanca estuary salt marshes. J. Soils Sedim. 8, 289–297.

Lee, J.A., Tallis, J.H., 1973. Regional and historical aspects of lead pollution in Britain. Nature 245, 216–218.

Loppi, S., Bonini, I., 2000. Lichens and mosses as biomonitors of trace elements in areas with thermal springs and fumarole activity (Mt. Amiata, central Italy). Chemosphere 41, 1333–1336.

Marcovecchio, J.E., Ferrer, L., 2005. Distribution and geochemical partitioning of heavy metals in sediments of the Bahia Blanca Estuary, Argentina. J. Coast Res. 21, 826–834.

Markert, B., Weckert, V., 1993. Time-and-site integrated long-term biomonitoring of chemical elements by means of mosses. Toxicol. Environ. Chem. 40, 43–56.

Markert, B., 1994. The biological system of the elements (BSE) for terrestrial plants (Glycophytes). Sci. Total Environ. 155, 221–228.

Markert, B., Oehlmann, J., Roth, M., 1997. General aspects of heavy metal monitoring by plants and animals. In: Subramanian, G., Iyengar, V. (Eds.), Environmental Biomonitoring- Exposure Assessment and Specimen Banking. ACS Symp. Ser, vol. 654. American Chemical Society, Washington DC, pp. 19–29.

Markert, B., Breure, A., Zechmeister, H. (Eds.), 2003. Bioindicators and Biomonitors. Principles, Concepts and Applications. Elsevier, Amsterdam.

Markert, B., Wuenschmann, S., Fraenzle, S., Wappelhorst, O., Weckert, V., Breulmann, G., Djingova, R., Herpin, U., Lieth, H., Schroeder, W., Siewers, U., Steinnes, E., Wolterbeek, B., Zechmeister, H., 2008. On the road from environmental biomonitoring to human health aspects: monitoring atmospheric heavy metal deposition by epiphytic/epigeic plants: present status and future needs. Int. J. Environ. Pollut. 32 (4), 486–498.

Namiesnik, J., Szefer, P. (Eds.), 2009. Analytical Measurements in Aquatic Environments. CRC Press, Boca Raton.

Ozturk, M., Yucel, E., Gucel, S., Serdal, S., Aksoy, A., 2008. Plants as biomonitors of trace elements pollution in soil. In: Prasad, M.N.V. (Ed.), Trace Elements – Nutritional Benefits, Environmental Contamination, and Health Implications. Wiley, pp. 721–742.

Pignata, M.L., Gudifio, G.L., Wannaz, E.D., Pla, R.R., Gonzalez, C.M., Carreras, H.A., Orellana, L., 2002. Atmospheric quality and distribution of heavy metals in Argentina employing Tillandsia capillaries as a biomonitor. Environ. Pollut. 120, 59–68.

Pla, R., Pignata, M.L., Carreras, H., Gonzales, C., 2009. 5th International Workshop on Biomonitoring Air Pollution, Buenos Aires, Argentina, 20–24 September, 2009.

Rauch, S., 2010. Platinum group elements in urban environments. Poster at the Urban Environmental Pollution Conference, June 20–23, 2010, Boston, US.

Ribeiro, A.P., Figueiredo, A.M.G., Sarkis, J.E.S, Hortellani, M.A., Markert, B. Pt, Pd, Rh and heavy metals in soils from major avenues of São Paulo City, Brazil, submitted for publication.

Simeonow, V., Simeonova, P., 2009. Receptor modelling in air quality assessment. In: Lecture given at the 5th International Workshop on Biomonitoring and Atmospheric Pollution (BIOMAP), 20–24 September, 2009, Buenos Aires, Argentina.

Trapp, S., Rein, A., 2009. Modelling of plant uptake and application in environmental science and engineering. RECETO PhD-course, 22–26 June. Technical University of Denmark, Kgs. Lyngby, DK.

Vianna, N.A., Gonçalves, D., Brandão, F., de Barros, R., Filho, G., Meire, R., Torres, J.P., Malm, O., D'Oliveira, A., Andrade, L., 2010. Assessment of heavy metals in the particulate matter of two Brazilian metropolitan areas by using *Tillandsia usneoides* as atmospheric biomonitor. Environ. Sci. Res. Int. 18 (3), 416–427.

Vutchkov, M., 2001. Biomonitoring of air pollution in Jamaica through trace-element analysis of epiphytic plants using nuclear and related analytical techniques. In: Co-ordinated Research Project on Validation and Application of Plants as Biomonitors of Trace Element Atmospheric Pollution, Analyzed by Nuclear and Related Techniques. IAEA, NAHRES-63, Vienna.

Wang, M., Chen, W., Markert, B., 2010. Effects of soil quality on fates of chlorimuron-ethyl in agricultural soils. Agrochimica. LIV-N4, 245–256.

Wang, M., Markert, B., Shen, W., Chen, W., Peng, C., Ouyang, Z., 2011. Microbial Biomass Carbon and Enzyme Activities of Urban Soils in Beijing. ESPR.

Wolterbeek, H.T., 2002. Biomonitoring of trace element air pollution: principles, possibilities and perspectives. Environ. Pollut. 120, 11–21.

Wolterbeek, H.T., Garty, J., Reis, M.A., Freitas, M.C., 2003. Biomonitors in use: lichens and metal air pollution. In: Markert, B., Breure, A.M., Zechmeister, H.G. (Eds.), Bioindicators and Biomonitors, Principles, Concepts and Applications. Elsevier, Amsterdam, pp. 377–419.

Wolterbeek, B., Sarmento, S., Verburg, T., 2010. Is there a future for biomonitoring of element air pollution? A review focused on a larger-scaled health-related (epidemiological) context. J. Radioanal. Nucl. Chem.. doi:10.1007/s10967-010-0637-y.

World Health Organization (WHO), 1996. Biological Monitoring of Chemical Exposure in the Workplace. Guidelines, vols. 1 & 2 Geneva.

Wuenschmann, S., Fraenzle, S., Markert, B., Zechmeister, H., 2008. Input and transfer of trace metals from food via mothermilk to the child: bioindicative aspects to human health. In: Prasad, M.N.V. (Ed.), Trace Elements – Nutritional Benefits, Environmental Contamination, and Health Implications. Wiley, pp. 555–592. Chapter 22.

Zhu, Y.G., Jones, K.C., 2010. Urbanisation and health in China. Lancet 376, 232–233.