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Aneta Helena Baczewska-Dąbrowska*, Barbara Gworek**, Wojciech Dmuchowski**

The Use of Mosses in Biomonitoring of Air Pollution in the Terrestrial Environment: A Review

* Ogród Botaniczny – Centrum Zachowania Różnorodności Biologicznej w Powsinie Polskiej Akademii Nauk: Polska Akademia Nauk Ogrod Botaniczny Centrum Zachowania Roznorodnosci Biologicznej w Powsinie, Warszawa, Poland;
e-mail: aneta.baczewska-dabrowska@ob.pan.pl
** Institute of Environmental Protection - National Research Institute, Warsaw, Poland

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Abstract
Environmental biomonitoring is an excellent supplement to instrumental methods of environmental quality assessment. The use of biological methods has many advantages (relatively low cost, independence from the source of energy in the field etc.). The limitation in the use of bioindication methods is the inability to compare the results with legal environmental pollution standards. Mosses are commonly used in air pollution monitoring. Mosses exhibit most of the characteristics attributed to effective bioindicators. The advantage of mosses over other bioindicators comes from the fact that the result depends only on-air pollution due to the lack of practical contact with the soil. Mosses are used in air pollution biomonitoring in two basic methods: naturally growing or transplanted to the researched area. They are most often used to assess air pollution by metals and other elements, but also by various organic compounds. A prerequisite for successful application of these methods is strict adherence to a recognised methodology and standardisation of all activities, such as random selection of measurement points. The article presents a critical analysis of the advantages and disadvantages of biomonitoring of air pollutants, along with a final recommendation for their use, provided that appropriate methodological rigor is maintained. An important advantage of mosses in biomonitoring is their relatively practical ease of application and interpretation of results, resulting in their widespread use.

1. INTRODUCTION

The use of plants in the assessment of air pollution has been used for many years. The pioneers were the Scandinavian researchers Rühling and Tyler [1968]. The scientific literature is dominated by the classic definition of terms related to environmental bioindication proposed by Markert et al. [2003]: '*A bioindicator is an organism (or part of an organism or a community of organisms) that contains information on the quality of the environment (or a part of the environment). A biomonitor, on the other hand, is an organism (or a part of an organism or a community of organisms) that contains information on the quantitative aspects of the quality of the environment*'. Wolterbeek et al. [2010] proposed a much shorter definition '*Biomonitoring, in a general sense, may be defined as the use of bio-organisms/materials to obtain (quantitative) information on certain characteristics of the biosphere*'. Bioindication methods are used especially when we are dealing with many contaminants occurring simultaneously. They are also helpful in learning about the history of changes in the degree of pollution over hundreds of years. The final effect of properly used bioindication is a more complete picture of the state of the environment than assessed only by physico-chemical methods [Gorovtsov et al. 2017; Chaudhuri, Roy 2023]. Presentations of the benefits and falsification of bioindication methods are presented in Table 1.

Indicator plants can be divided into two basic groups [Birungi et al. 2007]:

– Passive bioindicators are living organisms that naturally occur in the study area. The disadvantage of their use is often the difficulty of finding them throughout the area, and the advantages of the lack of maintenance and lower research costs. In return, the interpretation of results must take into account an important number of criteria related to the heterogeneity of the living conditions: soil quality, climatic conditions and season, genetic variability and metabolic state, heterogeneity of the spatial distribution of selected species.
– Active bioindicators are plants imported on the study site. The exposure of biological material in specific greenhouses generally makes it possible to be freed from the preceding.

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Table 1. Comparing the advantages and disadvantages of biological monitoring (compiled by authors)

Benefits	Disadvantages
Plants have a great ability to absorb and store pollutants	Plants absorb pollutants from the air and soil, which makes it difficult to interpret the results
Contaminants accumulated in plants or on their surface can be analysed by physical or chemical methods	The results of determining the content of pollutants in plants are not as precise as their measurements directly in the air
Plant research enables comprehensive and long-term measurements	Short-term fluctuations in the level of contamination distort the results
Plants can be used to identify sources of pollutant emissions, their dispersion and deposition	The need to use specific plant taxa
Relatively low cost	
Possibility to select a large number of measuring points over a large area	Difficulties in finding a suitable taxon in the entire study area
The use of plants enables a real assessment of the state of pollution and threat	It is not possible to compare the results with legal environmental pollution standards
Independence from the source of energy in the field. No risk of equipment damage	The condition and condition of the indicator plant depends on many factors such as climate change, pathogens, etc.

Bioindication methods make it possible to supplement physical and chemical tests, which usually show individual data of specific pollutants, not taking into account other pollutants and not taking into account the changing environmental conditions [Wolterbeek 2002]. Mosses, thanks to their properties discussed in further chapters, are very often used in the assessment of air pollution [e.g. Dołęgowska et al. 2021; Godzik 2020; Kapusta et al. 2020; Chaudhuri, Roy 2023].
The disadvantage of bioindication methods is the inability to obtain results with legal norms of pollutants determined by instrumental methods restrictions. In practice, it is often used to combine physicochemical measurements with bioindication observations. Zechmeister et al. [2003] showed that in the moss-bag method, the metal content in the exposed moss was correlated with the concentration in the air, which proves the effectiveness of this method. The effectiveness of moss testing methods in assessing air pollution is evidenced by the large number of international, national and local programs using these methods.

2. METHODOLOGY AND MAIN OBJECTIVE

The aim of our publication was to assess the possibility of using mosses in biomonitoring of air pollution in the terrestrial environment. The effectiveness of various methods and their practical applications are discussed. The main international programs using mosses are presented. The analysis partly used the literature review method proposed by Snyder [2019] for environmental analyses. The literature search method PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses) was also used [Diener, Mudu 2021; Sarkis-Onofre et al. 2021; Chaudhuri, Roy 2023]. As a result of this procedure, 95 publications were selected for our review. Database searches of SCOPUS, Science Direct, Web of Science and Google Scholar were performed using the following search terms: biomonitoring, pollution, moss, moss-bac, metals, nitrogen, PAHs, persistent organic pollutants (POPs), urban, agriculture, country side, industrial, radionuclides, metals smelter.
Critical discussion of all basic bioindication methods based on the latest literature are elements of novelty. Thus, 50% of the publications used were from the last four years, and 'historical' publications from the previous century were also cited.

3. MOSSES IN POLLUTION MONITORING

The selection of organisms bioindicators must be particularly careful and must meet many characteristics. The classic publications of Füreder and Reynolds [2003] and Gorovtsov et al. [2017] give a list of traits that must be met good bioindicators, most of which relate to the use of mosses:

- Taxonomic stability, easily recognised in the field by anyone;
- Relatively low sensitivity to pollution allowing to survive in conditions of moderate stress;
- Well-recognised conditions for growth and development;
- Numerous in various locations; and
- High capacity for quantification and standardisation, should show a consistent, increasing response.

Mosses are used in air pollution biomonitoring in three basic methods:
(1) Native mosses;

- Naturally growing mosses;
- Live mosses transplanted into the study area;

(2) Display of prepared dead dried moss.

Rühling and Tyler [1968] pioneered the study of heavy metal accumulation in naturally growing mosses as indicators of air pollution. The earliest studies were conducted in Sweden [Rühling, Tyler 1968], Denmark [Pakarinen, Tolonen 1976], Finland [Makinen 1977], Norway [Steinnes 1977] and Poland [Grodzińska 1978]. Mosses are mainly used in the monitoring of air pollution with metals, but they can also be effective in assessing nitrogen deposition [Díaz-Álvarez et al. 2018].

The properties of mosses have made them dominant for many years in biomonitoring in basic academic and practical research [Markert et al. 2020]. Advantages of using native mosses in bioindication of air pollution:

- Mosses are used as bioindicators of complex contamination: wet and dry deposition, which facilitates the assessment of total contamination [Markert et al. 2003; Aničić et al. 2009];
- Mosses take up water and minerals but also air pollutants almost exclusively from the air. Only minimal amounts of these components are taken up by some species from the soil [Ruchling, Tyler 1970; Jiang et al. 2018];
- Metals are practically not translocated inside the plant due to the lack of conductive tissues. transport of minerals between segments is limited [Schillin, Lehman 2002; Dragovič, Mihailovič 2009];
- strong correlation between pollutant deposition and accumulation in mosses [Macedo-Miranda et al. 2016; Oishi 2018];
- Very thin or even no cuticula, which results in easy transport of ions through the cell walls [Roberts et al. 2012];
- Extremely large surface area in relation to volume many times larger than in vascular plants [Adamo et al. 2007; Jiang et al. 2018];
- A relatively high tolerance of mosses to contamination [Itouga et al. 2017];
- Rapid development through repeated reproductive cycles through spores and vegetative fragments [Martin, Mallik 2017].

When using methods with mosses as bioindicators, one must remember that the measurements are not always precise. According to Bargagli [2016], the determination of Hg content in mosses cannot, however, be used to accurately determine atmospheric deposition, but only allows to locate Hg hot spots and changes in spatial distribution. An important issue is the methodological correctness of biomonitoring studies. Fernandez et al. [2015] evaluated 362 scientific publications discussing methodological and application studies of biomonitoring of metal deposition by mosses. The conclusions of these reviews indicated that most studies did not fully meet the criteria for valid scientific research. This fact does not undermine the desirability of conducting biomonitoring studies with mosses, but requires caution when formulating final conclusions.

3.1. Native and transplanted mosses

Live mosses in biomonitoring are used as two methods (i) native growing mosses and (ii) transplanted from a slightly polluted site to a heavily polluted one. Table 2 presents examples of the use of native mosses in pollution biomonitoring in different regions of the world. In 1985 Rühling et al launched the international research project *Survey of atmospheric heavy metal deposition in the Nordic countries in 1985 - monitored by moss analyses* (1987), initially covering eight locations in seven countries (Denmark, Finland, Norway, Sweden, Greenland, Svalbard, Iceland and northern part of West Germany), with Iceland using mosses *Hylocomium splendens* and *Pleurozium schreberi*. The studies covered nine metals: As, Cd, Cr, Cu, Fe, Pb, Ni, V, Zn. In 2005/6, 27 European countries already participated in this programme and the research was extended by Al, Sb and N [Harmens et al. 2010]. After pilot studies in 2010, POP (PAHs, PCBs, PBDEs, PFOS and dioxins) studies were included in the program in 2015, in which 36 countries, including non-European countries, have already participated (Armenia, Azerbaijan, Canada, Georgia, Mongolia, Tajikistan, Vietnam) [Harmens et al. 2015; Frontasyeva et al. 2020].

Table 3 shows changes (in %) in the median value of elements contained in European mosses in the years 1990–2015 (100% content was assumed for 1990), developed on the basis of Frontasyev et al. [2020]. The largest changes were found in the Pb content in mosses in the years 1990–2015, a decrease of as much as 87%, which is related to the cessation of the use of leaded gasoline to drive cars. The smallest decrease was determined for N by only 1.5% and Hg by 2%. The reason for this reduction was: elimination of large industrial emission sources the change in technology to less emitting ones; the use of filters; the abandonment of leaded gasoline; the replacement of coal with other raw materials, such as gas; and the increasing dissemination of green energy [EEA 2019; Schröder et al. 2023]. The EMEP report draws attention to the decrease in emissions from European sources is accompanied by an increase in the share of non-European emissions and ground emissions from historical sources [Ilyin et al. 2016].

Chaudhuri and Roy [2023] presented the contribution of individual species of mosses in the European Moss Survey Program in the study of metals: *Pleurozium schreberi* -39.6%, *Hypnum cupressiforme* -23.1%, *Hylocomium splendens* - 19.9%, *Pseudoscleropodium purum* 6.3%, and others - 11.2%. Mosses were used in the N studies: *Pleurozium schreberi* - 33.4%, *Hypnum cupressiforme* - 29.8%, *Pseudoscleropodium purum* -18%, *Hylocomium splendens* -13.1%, and other 5.6%.

Lee and Tallis [1973] determined the Pb content in mosses *Hypnum cupressiforme* from the botanical collection (herbarium) of the Manchester Museum in the years 1850–1900 and present (1972–1973) from an industrial region of Britain. They showed the highest values (> 200 ppm Pb) from the years 1850–1870 when there was a peak of metallurgical production. Roblin and Aherne [2020] proposed using mosses to assess microplastic air

Table 2. Examples of the use of live mosses in biomonitoring of air pollution

Air pollutant/deposition	Moss	Environment	Country	References
Native moss				
8 elements	*Hypnum cupressiforme*	countryside	Albania	Qarri et al. 2019
Fe, Cd, Cu, Pb, Zn	*Hypnum cupressiforme*	countryside	Albania	Lazo et al. 2022
37 elements	Multiple moss species	Pb-Zn smelter	Bułgaria	Hristozova et al. 2020
11 metals, N	*Hylocomium splendens, Hypnum cupressiforme, Pseudoscleropodium purum*	countryside	Europe, 15 countries	Harmens et al. 2015
12 metals	*Grimmia pulvinata*	cemeteries	France	Lequy et al. 2022
9 elements	*Pseudocleropodium purum Hypnum cupressiforme*	countryside	Kosowo	Maxhuni et al. 2016
6 elements	*Pleurozium schreberi*	countryside	Latvia	Tabors et al. 2023
35 elements	*Hypnum cupressiforme*	countryside	Moldova	Zinicovscaia et al. 2021
Cr, Cu, Fe, Ni, Pb, V, Zn	*Pleurozium schreberi, Scleropodium purum, Hypnum cupressiforme, Hylocomium splendens*	countryside	Netherlands, Germany, Poland	Herpin et al. 1996
27 elements	*Hypnum cupressiforme, Homalothecium lutescens, Homalothecium sericeum*	countryside	North Macedonia	Barandovski et al. 2020
Cd, Pb	*Pleurozium schreberi*	industrial	Poland	Dmuchowski et al. 2011a
S, δ^{34} S	*Pleurozium schreberi*	industrial	Poland	Kosior et al. 2015
PAHs	*Pleurozium schreberi*	Industrial,	Poland	Godzik et al. 2014
PBDEs, PCBs	*Pleurozium schreberi*	industrial	Poland	Kosior et al. 2017
17 elements	*Pleurozium schreberi*	countryside	Poland	Godzik 2020
Cd, Cr, Cu, Fe, Ni, Pb	*Pleurozium schreberi*	urban	Russia	Yushin et al. 2020
34 elements	*Pleurozium schreberi*	urban	Russia	Vergel et al. 2022
Pb isotopes, 7 metals	*Hylocomium* microphyllum	countryside	China	Zhou et al. 2021
Radionuclides: ^{210}Po,^{210}Pb, ^{226}Ra,^{7}Be,^{40}K,^{226}Ra,^{238}U,^{232}Th,^{137}Cs	*Leptobryum pyriforme, Ditrichum pallidum, Hypnodendron reinwardtii*	highway, urban, industrial	China	Zhong et al. 2019
NO_3^-	*Leskeella nervosa*	urban	Japan	Liu et al. 2012
	Brachytheciun plumosum	mountain		
Pb isotope ratios: ^{207}Pb/^{206}Pb,^{208}Pb/^{206}Pb	*Calohypnum plumiforme*	countryside	Japan	Oishi 2022
Fe, Al	*Calymperes afzelli, Acanthorrhynchium papillatum.*	tropical forest	Malaysia	Baharuddin, Zuhairi 2021
30 elements	*Barbula indica*	urban	Vietnam	Doan Phan et al. 2018
Cr, Zn, Cd, Pb	*Fabriona ciliaris, Leskea angustata*	countryside, urban parks	Mexico	Macedo-Miranda et al. 2016
N compounds	*Biaraun* sp.	urban, oak forest	Mexico	Díaz-Álvarez et al. 2016
21 elements	*Orthotrichum lyellii*	industrial	USA	Jovan et al. 2021
22 elements	*Orthotrichum lyellii*	urban	USA	Comess et al. 2021
PAHs	*Orthotrichum lyellii*	urban	USA	Jovan et al. 2022

Continued **Table 2.** Examples of the use of live mosses in biomonitoring of air pollution

Air pollutant/deposition	Moss	Environment	Country	References
Live transplanted				
S, δ^{34} S	*Pleurozium schreberi*	industrial	Poland	Kosior, et al. 2015
PBDEs, PCBs	*Pleurozium schreberi*	industrial	Poland	Kosior, et al. 2017
7 elements	*Pleurozium schreberi*	zinc smelter	Poland	Kaczmarek et al. 2017
17 elements	*Sphagnum palustre*	urban	Poland	Astel, et al. 2008
survivability	*Leucobryum glaucum*	urban, forest	Malaysia	Yatim, Azman 2021
8 elements	*Taxiphyllum giraldii, Thuidium sparsifolium*	traffic	Nepal	Shakya et al., 2012
18 elements	moss	still mill	Nigeria	Olise et al. 2019
Al, Fe, Mn, Pb, Zn	*Rhacocarpus purpurascens, Sphagnum* sp., *Thuidium delicatulum*	urban	Equator	Benítez et al. 2021
As, Cd, Hg, Pb	*Callicostella pallida, Versicularia versicularis, Isopterygium tenerum*	traffic	Paraguay	Coronel-Teixeira et al. 2022

PAHs - Polycyclic aromatic hydrocarbons
PCBs - *polychlorinated biphenyls*
PBDEs - Polybrominated diphenyl ethers

Table 3. Changes in (in %) the value of the median of elements contained in European mosses in the years 1990–2015 (100% content in 1995) (based on Frontasyeva et al. 2020)

Element	Median changes
Al	- 24*
An	- 38*
As	-13
Cd	- 63
Cr	- 24
Cu	- 30
Fe	- 22
Pb	- 82
Hg	- 2**
Ni	- 25
V	- 57
Zn	- 23
N	- 1.5*

*- 2005–2015
**- 1995–2015

pollution. Research in Ireland has shown that determining the content of microplastics in moss is an effective method of assessing the risk of this dangerous and so far little recognised pollution.

Samecka-Cymerman et al. [2005] compared the content of elements in a heavily polluted area: in the moss *Plagiothecium denticulatum* transplanted from uncontaminated areas for 60 days with naturally growing moss. They found higher contents of N, P, K and Ca in the native moss than in the transplanted moss, which they explained by the possibility of increasing the loss of these elements in the transplanted moss. Kosior et al. [2015] compared the S content in *Pleurozium schreberi* mosses from heavily polluted rural, urban and industrial areas' native moss with the transplanted from a relatively low-polluted control site. Native moss contained more S in rural and urban areas and less in industrial than the transplanted one. The conclusion of the study is that native moss is a more effective bioindicator in less polluted environments and worse in heavily polluted environments than transplanted.

The use of native mosses as biomonitors is a convenient way to determine the level of deposition of elements and other pollutants in the air. However, where samples of epiphytic mosses have been difficult to find at locations of interest, such as in urban and industrial areas, moss-bag methods has been employed as an option [Aničić et al. 2009; De Agostini et al. 2020]. Goodman and Roberts [1971] used the transplant method to assess air pollution in a heavily polluted area of Wales. The method involved moving moss (*Hypnum cupressiforme*) from a relatively unpolluted area to an industrial region. The method consisted in exposing a bag with moss coming from a 'clean' and a heavily polluted area for a certain period of time. After exposure, moss metal content was determined in the laboratory using standard physico-chemical methods. The moss-bag method uses the following features [Zechmeister et al. 2003; Aničić et al. 2009]:

3.2. Moss-bag method

The moss-bag method is based on the following properties of moss:

- Dry moss can absorb metals without significant limitations [Tavares, Vasconcelos 1996].
- The metal content in the moss exposed in the bag is proportional to its concentration in the air [Zechmeister et al. 2003; Aničić et al. 2009; Sang et al. 2021].



Figure 1.

Sphagnum are characterised by the ability to efficiently absorb metals in tissues and therefore have found widespread use in moss-bag methods [Ares 2012; Shvetsova et al. 2019]. Figure 1 shows a moss bag prepared for exposure. The method of moss exposure in the form of moss bags is by far the most commonly used. However, other forms of exposure were used, such as moss mats [Ares 2012].
Sang et al. [2021] compared two methods of using mosses *Barbula indica* in the assessment of air pollution with elements: moss bag and native moss. The results obtained by both methods gave a similar view of contamination. Native mosses accumulated more pollutants, but the moss-bag method enabled measurements in urban environments where native mosses did not occur or died during the summer drought. Świsłowski et al. [2022] assessed urban air pollution with seven metals (Cu, Zn, Cd, Pb, Mn, Fe, Hg), comparing three moss species: *Dicranum polysetum, Pleurozium schreberi* and *Sphagnum fallax*, as a moss bag and native moss transplants in boxes. *Pleurozium schreberi* was recommended as the best bioindicator accumulating the most and tested metals, and the moss-

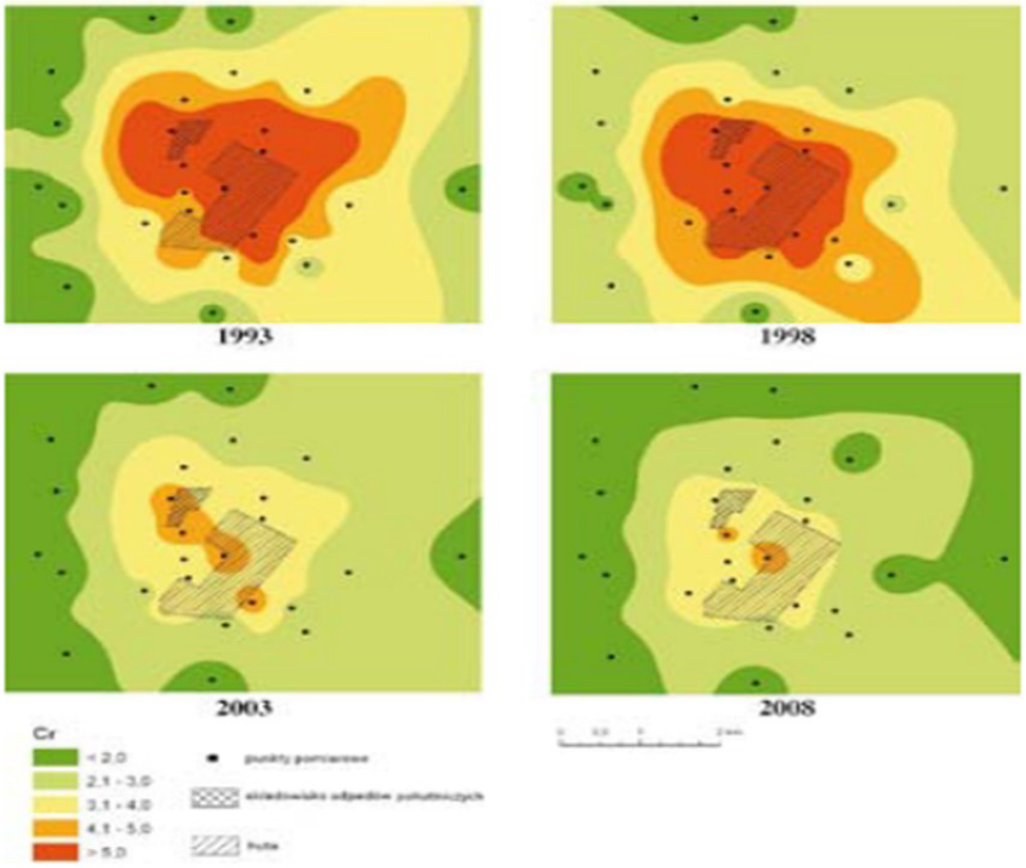


Figure 2.

Table 4. Examples of application of the moss-bag method in biomonitoring of air pollution

Air pollutant/ deposition	Moss	Environment	Country	References
Pb	*Hypnum cupressiforme*	industrial	England	Goodman ans Roberts 1971
Cd, Pb, Zn	*Sphagnum fallax*	urban	Poland	Dmuchowski and Bytnerowicz 2009
18 elements	*Hypnum cupressiforme*	industrial	Italy	Tretiach et al. 2011
Cd, Pb	*Sphagnum fallax*	industrial	Poland	Dmuchowski et al. 2001a
Cd, Cr, Pb	*Sphagnum fallax*	still mill	Poland	Dmuchowski et al. 2011b
19 elements	*Hypnum cupressiforme*	urban	Italy	Giordano et al. 2013
Particulate matter	*Sphagnum papillosum*	industrial	Finland	Salo and Mäkinen 2014
PAHs*, 39 elements	*Hypnum cupressiforme*	urban	Italy	Capozzi et al. 2016a
10 elements	*Pseudoscleropodium purum*	agricultural, urban, industrial	Austria, Italy, Spain	Capozzi et al. 2016b
Sb, Cu, Cr	*Sphagnum girgensohnii, Hypnum cupressiforme*	urban	Serbia	Vuković et al. 2016
7 elements	*Pleurozium* ssp, *Polytrichum* ssp, *Rhytidiadelphus* ssp.	mining	Slovakia	Demková et al. 2017
Particulate matter, 23 elements	*Pseudoscleropodium purum*	agricultural, urban, industrial	Austria, Italy, Spain	Di Palma et al. 2017
9 elements	*Sphagnum fallax*, *Dicranum polysetum*	urban	Poland	Świsłowski et al. 2022
^{134}Cs, ^{137}Cs	*Hypnum cupressiforme, Hypnum plumaeforme*	Fukushima breakdown	Japan	Di Palma et al. 2022
12 elements	*Taxiphyllum taxirameum*	agricultural, urban, traffic, industrial	China	Mao et el. 2022
Microplastic	*Pleurozium schreberi*	urban, traffic. rural	Canada	Bertrim and Aherne 2023
PAHs*	*Hypnum plumaeforme*	urban	Malysia	Hanifah and Sani 2023
35 elements	*Hypnum cupressiforme, Sphagnum girgensohnii*	urban, rural	Southeastern Europe, 10 countries	Urošević et al. 2023

*PAHs - Polycyclic aromatic hydrocarbons

bag method was recommended for biomonitoring due to the much higher content of metals than native moss.
Figure 2 shows an exemplary application of the moss-bag method in the assessment of air pollution with chromium in the area of heavy pollution from the steel mill source. The use of this method made it possible to show changes in air pollution over a long period (15 years) based on a large number of measurement points and the same research material [Dmuchowski et al. 2011b]. Table 4 presents examples of the use of moss-bag methods in pollution biomonitoring in different regions of the world.

4. CONCLUSION

Bioindication methods can be an important element in environmental monitoring. The relatively low cost and the possibility of using a large number of measurement points make them a perfect complement to the instrumental methods. Methods using mosses as effective bioindicators are particularly recommended. It can be said that in recent years, moss research has dominated biomonitoring around the world. The advantage of mosses over other bioindicators is that they collect pollutants only from the air. These methods have been used in international research programmes. Other methods that have also found wide application is the method with prepared moss – 'moss bag'. The moss exposed in the bags can be displayed in places where moss does not occur naturally, such as urban and industrial environments. Features of biomonitoring, such as the relative simplicity of all elements: collecting moss samples, simple and cheap technical equipment, no need to employ super specialists, easy interpretation of the results obtained. All these properties cause that the biomonitoring of elements will develop and increase the scale and geographical scope of research The significant value of information from biomonitoring can only be discussed when it is linked to databases on the environment, pollutant

emissions, changes in ecosystems, living standards and health of the population. The development of analytical physicochemical methods and computer science will not eliminate bioindication methods, which will remain as a supplement to more advanced methods. A threat to the use of bioindication with mosses is not following strict methodologies. Over interpretation of results and drawing unauthorised conclusions may discourage the use of mosses in biomonitoring.

REFERENCES AND LEGAL ACTS

ADAMO P., CRISAFULLI P., GIORDANO S., MINGANTI V., MODENESI P., MONACI F., PITTATO E., TRETIACH M., BARGAGLI, R. 2007. Lichen and moss bags as monitoring devices in urban areas. Part II: Trace element content in living and dead biomonitors and comparison with synthetic materials. Environmental Pollution 146, 2: 392-399. https://doi.org/10.1016/j.envpol.2006.03.047

ANIČIĆ M., TOMAŠEVIĆ M., TASIĆ M., RAJŠIĆ S., POPOVIĆ A., FRONTASYEVA M.V., LIERHAGEN S., STEINNES E. 2009. Monitoring of trace element atmospheric deposition using dry and wet moss bags: accumulation capacity versus exposure time. Journal of Hazardous Materials 171: 182-188. https://doi.org/10.1016/j.jhazmat.2009.05.112

ARES A., ABOAL J.R., CARBALLEIRA A., GIORDANO S., ADAMO P., FERNÁNDEZ J.A. 2012. Moss bag biomonitoring: a methodological review. Science of the Total Environment 432: 143-158. https://doi.org/10.1016/j.scitotenv.2012.05.087

ASTEL A., ASTEL K., BIZIUK M. 2008. PCA and Multidimensional Visualization Techniques United to Aid in the Bioindication of Elements from Transplanted Sphagnum Palustre Moss Exposed in the Gdansk City Area. Environmental Science and Pollution Research 15, 1: 41-50. https://doi.org/10.1065/espr2007.05.422

BAHARUDDIN Z.M., ZUHAIRI A.H. 2021. Moss as bioindicators for pollution at fraser hill and cameron highland pahang Malaysia. Planning Malaysia 19, 2: 263-274.

BARANDOVSKI L., STAFLOV T., SAJN R., FRONTASYEVA M., ANDONOVSKA K.V. 2020. Atmospheric heavy metal deposition in North Macedonia from 2002 to 2010 studied by moss biomonitoring technique. Atmosphere 11, 929: 1-23. https://doi.org/10.3390/atmos11090929

BARGAGLI R. 2016. Moss and lichen biomonitoring of atmospheric mercury: A review. Science of the Total Environment 572: 216-231. https://doi.org/10.1016/j.scitotenv.2016.07.202

BENÍTEZ Á., ARMIJOS L., CALVA J. 2021. Monitoring Air Quality with Transplanted Bryophytes in a Neotropical Andean City. Life, 11(8), 821. https://doi.org/10.3390/life11080821

BERTRIM C., AHERNE J. 2023. Moss Bags as Biomonitors of Atmospheric Microplastic Deposition in Urban Environments. Biology 12, 2: 149. https://doi.org/10.3390/biology12020149

BIRUNGI Z., MASOLA B., ZARANYIKA M.F., NAIGAGA I., MARSHALL B. 2007. Active biomonitoring of trace heavy metals using fish (*Oreochromis niloticus*) as bioindicator species. The case of Nakivubo wetland along Lake Victoria. Physics and Chemistry of the Earth, Parts A/B/C 2 15-18: 1350-1358. https://doi.org/10.1016/j.pce.2007.07.034

CAPOZZI F., GIORDANO S., ABOAL J.R., ADAMO P., BARGAGLI R., BOQUETE T., DI PALMA A., REA C., RESKI R., SPAGNUOLO V., STEINBAUER K., TRETIACH M., VARELA Z., ZECHMEISTER H., FERNÁNDEZ, J.A. 2016b. Best options for the exposure of traditional and innovative moss bags: a systematic evaluation in three European countries. Environmental Pollution 214: 362-373. https://doi.org/10.1016/j.envpol.2016.04.043

CAPOZZI F., GIORDANO S., DI PALMA A., SPAGNUOLO V., DE NICOLA F., ADAMO P. 2016a. Biomonitoring of atmospheric pollution by moss bags: discriminating urban-rural structure in a fragmented landscape. Chemosphere 149: 211-218. https://doi.org/10.1016/j.chemosphere.2016.01.065

CHAUDHURI S., ROY M. 2023. Global ambient air quality monitoring: *Can mosses help?* A systematic meta-analysis of literature about passive moss biomonitoring. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-023-03043-0

COMESS S., DONOVAN G., GATZIOLIS D., DEZIEL N.C. 2021. Exposure to atmospheric metals using moss bioindicators and neonatal health outcomes in Portland, Oregon. Environmental Pollution 284: 117343. https://doi.org/10.1016/j.envpol.2021.117343

CORONEL-TEIXEIRA R., CAÑIZA B., FRETES J., RODRÍGUEZ M., PASTEN M., ESCURRA C.M., PÉREZ-BEJARANO D. 2022. Relevant aspects on biomonitoring of heavy metal concentration in environmental air in Asunción city. Revista científica ciencias de la salud, 4(1), 75-83. https://doi.org/10.53732/rccsalud/04.01.2022.75

DE AGOSTINI A., CORTIS P., COGON A. 2020. Monitoring of Air Pollution by Moss Bags around an Oil Refinery: A Critical Evaluation over 16 Years. Atmosphere 11: 272. https://doi.org/10.3390/atmos11030272

DEMKOVÁ L., BOBUĽSKÁ L., ÁRVAY J., JEZNÝ T., DUCSAY L. 2017. Biomonitoring of heavy metals contamination

by mosses and lichens around Slovinky tailing pond (Slovakia), Journal of Environmental Science and Health, Part A 52 1: 30-36. https://doi.org/10.1080/10934529.2016.1221220

DI PALMA A., ADAMO P., DOHIT., FUJIWARA K., HAGIWARA H., KITAMURA A., SAKODA A., SATO K., IIJIMA K. 2022. Testing mosses exposed in bags as biointerceptors of airborne radiocaesium after the Fukushima Dai-ichi Nuclear Power Station accident. Chemosphere 308: 136179. https://doi.org/10.1016/j.chemosphere.2022.136179

DI PALMA A., CAPOZZI F., SPAGNUOLO V., GIORDANO S., ADAMO P. 2017. Atmospheric particulate matter intercepted by moss-bags: Relations to moss trace element uptake and land use. Chemosphere 176: 361-368. https://doi.org/10.1016/j.chemosphere.2017.02.120

DÍAZ-ÁLVAREZ E.A., LINDIG-CISNEROS R., DE LA BARRERA E. 2018. Biomonitors of atmospheric nitrogen deposition: potential uses and limitations. Conservation Physiology 6, 1: coy011. https://doi.org/10.1093/conphys/coy011

DÍAZ-ÁLVAREZ E.A., REYES-GARCÍA C., DE LA BARRERA E. 2016. A δ^{15} N assessment of nitrogen deposition for the endangered epiphytic orchid *Laelia speciosa* from a city and an oak forest in Mexico. Journal of Plant Research 129: 863-872. https://doi.org/10.1007/s10265-016-0843-y

DIENER A., MUDU P. 2021. How can vegetation protect us from air pollution? A critical review on green spaces' mitigation abilities for air-borne particles from a public health perspective-with implications for urban planning. Science of the Total Environment 796: 148605. https://doi.org/10.1016/j.scitotenv.2021.148605

DMUCHOWSKI W., BYTNEROWICZ A. 2009. Long-term (1992–2004) record of lead, cadmium, and zinc air contamination in Warsaw, Poland: Determination by chemical analysis of moss bags and leaves of Crimean linden. Environmental Pollution 157, 12: 3413-3421. https://doi.org/10.1016/j.envpol.2009.06.019

DMUCHOWSKI W., GOZDOWSKI D., BACZEWSKA A.H. 2011a. Comparison of four bioindication methods for assessing the degree of environmental lead and cadmium pollution. Journal of Hazardous Materials 197: 109-118. https://doi.org/10.1016/j.jhazmat.2011.09.062

DMUCHOWSKI W., GWOREK B., GOZDOWSKI D., BACZEWSKA A., MACIASZEK D. 2011b. Evaluation of changes in air pollution with lead, zinc, and chromium in the steel mill region in Warsaw in 1993-2008. Przemysł Chemiczny 90: 218-221. (in polish)

DOAN PHAN T.D., TRINH T.T.M., KHIEM L.H., FRONTASYEVA M.V., QUYET N.H. 2018. Study of airborne trace element pollution in central and southern Vietnam using moss (*Barbula indica*) technique and neutron activation analysis. Asia-Pacific Journal of Atmospheric Sciences 55, 2: 247-253. https://doi.org/10.1007/s13143-018-0065-4

DOŁĘGOWSKA S., GAŁUSZKA A. MIGASZEWSKI Z.M. 2021. Significance of the long-term biomonitoring studies for understanding the impact of pollutants on the environment based on a synthesis of 25-year biomonitoring in the Holy Cross Mountains, Poland. Environmental Science and Pollution Research 28: 10413–10435. https://doi.org/10.1007/s11356-020-11817-6

DRAGOVIČ S., MIHAILOVIČ N. 2009. Analysis of mosses and topsoils for detecting sources of heavy metal pollution: Multivariate and enrichment factor analysis. Environmental Monitoring and Assessment 157, 1-4: 383–390. https://doi.org/10.1007/s10661-008-0543-8

FERNÁNDEZ J.A., BOQUETE M.T., CARBALLEIRA A., ABOAL J.R. 2015. A critical review of protocols for moss biomonitoring of atmospheric deposition: sampling and sample preparation. Science of the Total Environment 517: 132-150. https://doi.org/10.1016/j.scitotenv.2015.02.050

EUROPEAN ENVIRONMENT AGENCY (EEA). 2019. European Union emission inventory report 1990–2017 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP). EEA report no 08/2019, Copenhagen, Denmark.

FRONTASYEVA M., HARMENS H., UZHINSKIY A., CHALIGAVA O. 2020. Mosses as biomonitors of air pollution: 2015/2016 survey on heavy metals, nitrogen and POPs in Europe and beyond. In: Report of the ICP Vegetation Moss Survey Coordination Centre. Joint Institute for Nuclear Research Dubna, Russian Federation.

FÜREDER L., REYNOLDS J.D. 2003. Is austropotamobiuspallipes a good bioindicator? Bulletin Français de la Pêche et de la Pisciculture 370-371: 157-163. https://doi.org/10.1051/kmae:2003011

GIORDANO S., ADAMO P., SPAGNUOLO V., TRETIACH M., BARGAGLI R. 2013. Accumulation of airborne trace elements in mosses, lichens and synthetic materials exposed at urban monitoring stations: towards a harmonisation of the moss-bag technique. Chemosphere 90, 2: 292-299. https://doi.org/10.1016/j.chemosphere.2012.07.006

GODZIK B. 2020. Use of bioindication methods in national, regional and local monitoring in Poland - Changes in the air pollution level over several decades. Atmosphere 11, 2: 143. https://doi.org/10.3390/atmos11020143

GODZIK B., SZAREK-ŁUKASZEWSKA G., KAPUSTA P., STĘPIEŃ K. 2014. PAHs concentrations in Poland using moss *Pleurozium schreberi* as bioindicator. Polish Botanical Journal 59, 1: 137-144. https://doi.org/10.2478/pbj-2014-0019

GOODMAN G.T., ROBERTS T.M. 1971. Plants and soil as indicators of metals in the air. Nature 231: 287-292. https://doi.org/10.1038/231287a0

GOROVTSOV A., RAJPUT V.D., GORBOV S., VASILCHENKO N. 2017. Bioindication-based approaches for sustainable management of urban ecosystems. In: Singh R., Kumar S. (Eds.), Green Technologies and Environmental Sustainability, Springer, 203-228. https://doi.org/10.1007/978-3-319-50654-8_9

GRODZIŃSKA K. 1978. Mosses bioindicators of heavy metal pollution in Polish national parks. Water, Air, & Soil Pollution 9: 83-97. https://doi.org/10.1007/BF00185749

HANIFAH N.A., SANI M.S.A. 2023. Moss and Polyaromatic Hydrocarbon in Malaysia: A Recent Ten-Year Evaluation. Halalpshere 3, 1: 64-89. https://doi.org/10.31436/hs.v3i1.63

Harmens H., Norris D.A., Steinnes E., Kubin E., Piispanen J., Alber R., et al. 2010. Mosses as biomonitors of atmospheric heavy metal deposition: spatial patterns and temporal trends in Europe. Environmental Pollution 158, 10: 3144-3156. https://doi.org/10.1016/j.envpol.2010.06.039

HARMENS H., NORRIS D.A., SHARPS K., MILLS, G., ALBER R., ALEKSIAYENAK Y., BLUM O., CUCU-MAN S.M., DAM M., DE TAMMERMAN L. et al. 2015. Heavy metal and nitrogen concentrations in mosses are declining across Europe whilst some "hotspots" remain in 2010. Environmental Pollution 200: 93-104. https://doi.org/10.1016/j.envpol.2015.01.036

HERPIN U., BERLEKAMP J., MARKERT B., WOLTERBEEK B., GRODZINSKA K., SIEWERS U., LIETH H., WECKERT V. 1996. The distribution of heavy metals in a transect of the three states the Netherlands, Germany and Poland, determined with the aid of moss monitoring. The Science of the Total Environment 187: 185-198. https://doi.org/10.1016/0048-9697(96)05141-8

HRISTOZOVA G., MARINOVA S., FRONTASAYEVA M.V. 2019. Atmospheric deposition studies based on a 20-year period of moss biomonitoring in the Vicinity of a Lead-zinc Plant. in Kardzhali, Bulgaria (1995/6-2015/16). AIP Conference Proceedings 2163: 050001. https://doi.org/10.1063/1.5130105

ILYIN I., ROZOVSKAYA O., TRAVNIKOV O., VARYGINA M., AAS W., PFAFFHUBER K.A. 2016. Assessment of heavy metal transboundary pollution, progress in model development and mercury research. EMEP Status Report, 2/2016. MCS-E & CCC, Moscow, Russia & Kjeller, Norway

ITOUGA M., HAYATSU M., SATO M., TSUBOI Y., KATO Y., TOYOOKA K., SUZUKI S., NAKATSUKA S., KAWAKAMI S., KIKUCHI J., HITOSHI SAKAKIBARA H. 2017. Protonema of the moss *Funaria hygrometrica* can function as a lead (Pb) adsorbent. PLoS One 12: 1-19. https://doi.org/10.1371/journal.pone.0189726

JIANG Y., FAN M., HU R., ZHAO J., WU Y. 2018. Mosses are better than leaves of vascular plants in monitoring atmospheric heavy metal pollution in urban areas. International Journal of Environmental Research and Public Health Public Health 15: 1105. https://doi.org/10.3390/ijerph15061105

JOVAN S.E., MONLEON V.C., DONOVAN G.H., GATZIOLIS D., AMACHER M.C. 2021. Small-scale distributions of polycyclic aromatic hydrocarbons in urban areas using geospatial modeling: A case study using the moss *Orthotrichum lyellii* in Portland, Oregon, U.S.A. Atmospheric Environmental 256: 118433. https://doi.org/10.1016/j.atmosenv.2021.118433

JOVAN S.E., ZUIDEMA C., DERRIEN M.M., BIDWELL A.L., BRINKLEY W., BARHIL R., SMITH R.J., BARNHILL R., GOULD L., RODRÍGUEZ A.J., AMACHER M.C., ABEL T.D., LOPEZ P. 2022. Heavy metals in moss guide environmental justice investigation: A case study using community science in Seattle, WA, USA. Ecosphere 13, 6: e4109. https://doi.org/10.1002/ecs2.4109

KACZMAREK K., ŚWISŁOWSKI P., RAJFUR M. 2017. The active biomonitoring using mosses as bioindicators Near Miasteczko Ślaskie. Proceedings of ECOpole 11: 507-516. https://doi.org/10.2429/proc.2017.11(2)055

KAPUSTA P., STAKENK M., SZAREK-LUKASZWSKA G., GODZIK B. 2020. Long-term moss monitoring of atmospheric deposition near a large steelworks reveals the growing importance of local non-industrial sources of pollution. Chemosphere 230: 29–39. https://doi.org/10.1016/j.chemosphere.2019.05.058

KOSIOR G., CIĘŻKA M., GÓRKA M., SAMECKA-CYMERMAN A., KOLON K., KEMPERS A.J., JĘDRYSEK M.O. 2015. $\delta^{34}S$ values and S concentrations in native and transplanted *Pleurozium schreberi* in a heavily industrialised area. Ecotoxicology and Environmental Safety 118: 112-117. https://doi.org/10.1016/j.ecoenv.2015.04.018

KOSIOR G., PŘIBYLOVÁ P., VAŇKOVÁ L., KUKUČKA P., AUDY O., KLÁNOVÁ J SAMECKA-CYMERMAN A., MRÓZ L., KEMPERS A.J. 2017. Bioindication of PBDEs and PCBs by native and transplanted moss *Pleurozium schreberi*. Ecotoxicology and Environmental Safety 143: 136-142. https://doi.org/10.1016/j.ecoenv.2017.05.025

LAZO P., KIKA A., QARRI F., BEKTESHI L., ALLAJBEU S., STAFILOV T. 2022. Air Quality Assessment by Moss Biomonitoring and Trace Metals Atmospheric Deposition. Aerosol Air Quality Research 22: 220008. https://doi.org/10.4209/aaqr.220008

LEE J., TALLIS J. 1973.Regional and Historical Aspects of Lead Pollution in Britain. Nature 245: 216-218. https://doi.org/10.1038/245216a0

LEQUY E., MEYER C., VIENNEAU D., BERR C., GOLDBERG M., ZINS M., LEBLOND S., DE HOOGH K., JACQUEMIN B. 2022. Modeling exposure to airborne metals using moss biomonitoring in cemeteries in two urban areas around Paris and Lyon in France. Environmental Pollution 303: 119097. https://doi. org/10.1016/j.envpol.2022.119097

LIU X.Y., KOBA K., TAKEBAYASHI Y., LIU C.Q., FANG Y.T., YOH M. 2012. Preliminary insights into $\delta^{15}N$ and $\delta^{18}O$ of nitrate in natural mosses: A new application of the denitrifier method. Environmental Pollution 162: 48-55. https://doi.org/10.1016/j.envpol.2011.09.029

MACEDO-MIRANDA G., AVILA-PÉREZ P., GIL-VARGAS P., ZARAZÚA G., SÁNCHEZ-MEZA J.C., ZEPEDA-GÓMEZ C., TEJEDA S. 2016. Accumulation of heavy metals in mosses: a biomonitoring study. *S*pringerPlus 5: 715. https://doi.org/10.1186/s40064-016-2524-7

MAKINEN A. 1977. Moss-and peat-bags in air pollution monitoring. Suo 28: 79-88.

MAO H.T., WANG X.M., WU N., CHEN L.X., YUAN M., HU J.C., CHEN Y.E. 2022. Temporal and spatial biomonitoring of atmospheric heavy metal pollution using moss bags in Xichang. Ecotoxicology and Environmental Safety 239: 113688. https://doi.org/10.1016/j.ecoenv.2022.113688

MARKERT B.A., BREURE A.M., ZECHMEISTER H.G. 2003. Definitions, strategies and principles for bioindication/biomonitoring of the environment. Trace Metals and other Contaminants in the Environment 6: 3-39. Elsevier. https://doi.org/10.1016/S0927-5215(03)80131-5

MARKERT B., ABDALLAH N., AKSOY A., AMMARI T., ARIAS A., AZAIZEH H. et al. 2020. Information gain in environmental monitoring through bioindication and biomonitoring methods ("B & B technologies") and phytoremediation processes–with special reference to the Biological System of Chemical Elements (BSCE) under specific consideration. Bioactive Compounds in Health and Disease 3, 11: 214-250. https://www.doi.org/10.31989/bchd.v3i11.760

MARTIN P.S., MALLIK A.U. 2017. The status of non-vascular plants in trait-based ecosystem function studies. Perspectives in Plant Ecology, Evolution and Systematic 27, 80: 1-8. https://doi.org/10.1016/j.ppees.2017.04.002

MAXHUNI A., LAZO P., KANE S., QUARRI F., MARKU E., HARRY H. 2016. First survey of atmospheric heavy metal deposition in Kosovo using moss biomonitoring. Environmental Science and Pollution Research International 2, 1: 744–755. https://doi.org/10.1007/s11356-015-5257-1

OISHI Y. 2018. Comparison of moss and pine needles as bioindicators of transboundary polycyclic aromatic hydrocarbon pollution in central Japan. Environmental Pollution 234: 330-338. https://doi.org/10.1016/j.envpol.2017.11.035

OISHI Y. 2022. Moss biomonitoring using lead isotope ratios requires careful attention: Evaluation of transboundary pollutants in Japan. Atmospheric Environment 275: 119004. https://doi.org/10.1016/j.atmosenv.2022.119004

OLISE F.S., OGUNDELE L.T., OLAJIRE M.A., OWOADE O.K., OLOYEDE F.A., FAWOLE O.G., EZEH G.C. 2019. Biomonitoring of environmental pollution in the vicinity of iron and steel smelters in southwestern Nigeria using transplanted lichens and mosses. Environmental Monitoring and Assessment 191: 691. https://doi.org/10.1007/s10661-019-7810-8

PAKARINEN P., TOLONEN K. 1976. Regional survey of heavy metals in peat mosses *(Sphagnum)*. Ambio 5, 1*:* 38-40.

QARRI F., LAZO P., ALLAJBEU S., BEKTESHI L., STAFLOV T. 2019. The evaluation of air quality in Albania by moss biomonitoring and metals atmospheric deposition. Archives of Environmental Contamination and Toxicology 76: 554–571. https://doi.org/10.1007/s00244-019-00608-x

ROBERTS A.W., ROBERTS E.M., HAIGLER C.H. 2012. Moss cell walls: structure and biosynthesis. Frontiers in Plant Science 3: 1-8. https://doi.org/10.3389/fpls. 2012.00166

ROBLIN B., AHERNE J. 2020. Moss as a biomonitor for the atmospheric deposition of anthropogenic microfibres. Science of the Total Environment 715: 136973. https://doi.org/10.1016/j.scitotenv.2020.136973

RUČHLING A.Ę., TYLER G. 1970. Sorption and retention of heavy metals in the woodland moss *Hyalocomium splendens*. Oikos 21: 248.

RÜHLING A., RASMUSSEN L., PILEGAARD K., MAKINEN A, STEINNES E. 1987. Survey of Atmospheric Heavy Metal Deposition in the Nordic Countries in 1985 - Monitored by Moss Analyses. Nordisk Ministerrad, NORD 1987, 21,

RÜHLING A., TYLER G. 1968. An ecological approach to the lead problem. Botaniska Notiser 121, 3: 321-342.

SALO H., MÄKINEN J. 2014. Magnetic biomonitoring by moss bags for industry-derived air pollution in SW Finland. Atmospheric Environment 97: 19-27. https://doi.org/10.1016/j.atmosenv.2014.08.003

SAMECKA-CYMERMAN A., KOLON K., KEMPERS A.J. 2005. Differences in Concentration of Heavy Metals Between Native and Transplanted *Plagiothecium denticulatum*: A Case Study of Soils Contaminated by Oil Well Exudates in South East Poland. Archives of Environmental Contamination Toxicology 49: 317-321. https://doi.org/10.1007/s00244-004-0161-6

SANG N.T.M., KHIEM L.H., SON N.A. 2021. Comparison of moss bag and native moss technique in monitoring airborne particulate and toxic elements. Journal of Science and Technology Development 24, 2: 1967-1974. 10.32508/stdj.v24i2.2531

SARKIS-ONOFRE R., CATALÁ-LÓPEZ F., AROMATARIS E., LOCKWOOD C. 2021. How to properly use the PRISMA Statement. Systematic Reviews 10: 117. https://doi.org/10.1186/s13643-021-01671-z

SCHILLIN J.S., LEHMAN M.E. 2002. Bioindication of atmospheric heavy metal deposition in the Southeastern US using the moss *Thuidium delicatulum*. Atmospheric Environment 36: 1611-1618. https://doi.org/10.1016/S1352-2310(02)00092-4

SCHRÖDER W., NICKEL S., DREYER A., VÖLKSEN B. 2023. Accumulation of Atmospheric Metals and Nitrogen Deposition in Mosses: Temporal Development between 1990 and 2020, Comparison with Emission Data and Tree Canopy Drip Effects. Pollutants 3, 1: 89-101. https://doi.org/10.3390/pollutants3010008

SHAKYA K., CHETTRI M.K., SAWIDIS T. 2012. Use of mosses for the survey of heavy metal deposition in ambient air of the Kathmandu valley applying active monitoring technique. Ecoprint 19: 17-29.

SHVETSOVA M.S., KAMANINA I.Z., FRONTASYEVA M.V., MADADZADA A.I., ZINICOVSCAIA I.I., PAVLOV S.S., VERGEL K.N., YUSHIN N.S. 2019. Active Moss Biomonitoring Using the "Moss Bag Technique" in the Park of Moscow. Physics of Particles and Nuclei Letters 16: 994-1003. https://doi.org/10.1134/S1547477119060293

SNYDER H. 2019. Literature review as a research methodology: An overview and guidelines. The Journal of Business Research 104: 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039

STEINNES E. 1977. Atmospheric deposition of trace elements in Norway studied by means of moss analysis. Kjeller Report 154, Institutt for Atomenergi, Norway.

ŚWISŁOWSKI P., NOWAK A., RAJFUR M. 2022. Comparison of Exposure Techniques and Vitality Assessment of Mosses in Active Biomonitoring for Their Suitability in Assessing Heavy Metal Pollution in Atmospheric

Aerosol. Environmental Toxicology and Chemistry 41, 6: 1429-1438. https://doi.org/10.1002/etc.5321

TABORS G., BRŪMELIS G., NIKODEMUS O., DOBKEVIČA L., VILIGURS K. 2023. Decreased atmospheric deposition of heavy metals shown by long-term monitoring using the moss *Pleurozium schreberi*. Environmental Science and Pollution Research. https://doi.org/10.21203/rs.3.rs-2559234/v1

TAVARES H.M., VASCONCELOS M.T.S. 1996. Comparison of lead levels collected by *Sphagnum auriculatum* and by a low-volume aerosol sampler in the urban atmosphere of Oporto. Toxicological Environmental Chemistry 54, 1-4: 195-209. https://doi.org/10.1080/02772249609358312

TRETIACH M., PITTAO E., CRISAFULLI P., ADAMO P. 2011. Influence of exposure sites on trace element enrichment in moss-bags and characterization of particles deposited on the biomonitor surface. Science of the Total Environment 409, 4: 822-830. https://doi.org/10.1016/j.scitotenv.2010.10.02

UROŠEVIĆ M.A., LAZO P., STAFILOV T. M. NEČEMER M., BAČEVA ANDONOVSKA K., BALABANOVA B., HRISTOZOVA G., PAPAGIANNIS S., STIHI C., SULJKANOVIĆ M., ŠPIRIĆ Z., VASSILATOU V., VOGEL-MIKUŠ K. 2023. Active biomonitoring of potentially toxic elements in urban air by two distinct moss species and two analytical techniques: a pan-Southeastern European study. Air Quality, Atmosphere & Health 16: 595-612. https://doi.org/10.1007/s11869-022-01291-z

VERGEL K., ZINICOVSCAIA I., YUSHIN N., CHALIGAVA O., NEKHOROSHKOV P., GROZDOV D. 2022. Moss Biomonitoring of Atmospheric Pollution with Trace Elements in the Moscow Region, Russia. Toxics 10, 2: 66. https://doi.org/10.3390/toxics10020066

VUKOVIĆ G., ANIČIĆ U., ŠKRIVANJ S., MILIĆEVIĆ T., DIMITRIJEVIĆ D., TOMAŠEVIĆ M., POPOVIĆ A. 2016. Moss bag biomonitoring of airborne toxic element decrease on a small scale: a street study in Belgrade, Serbia. Science of the Total Environment 542: 394–403 https://doi.org/10.1016/j.scitotenv.2015.10.091

WOLTERBEEK B. 2002. Biomonitoring of trace element air pollution: Principles, possibilities and perspectives. Environmental Pollution 120: 11–21. https://doi.org/10.1016/S0269-7491(02)00124-0

WOLTERBEEK B., SARMENTO S., VERBURG T. 2010. Is there a future for biomonitoring of elemental air pollution? A review focused on a larger-scaled health-related (epidemiological) context. Journal of Radioanalytical and Nuclear Chemistry 286: 195-210. 10.1007/s10967-010-0637-y

YATIM N.M,. AZMAN N.I.A. 2021. Moss as bio-indicator for air quality monitoring at different air quality environment. International Journal of Engineering and Advanced Technology 10: 43-7. https://doi.org/10.35940/ijeat.E2579.0610521

YUSHIN N., CHALIGAVA O., ZINICOVSCAIA I., VERGEL K., GROZDOV D. 2020. Mosses as bioindicators of heavy metal air pollution in the lockdown period adopted to cope with the COVID-19 pandemic. Atmosphere 11, 11: 1194.

ZECHMEISTER H.G., GRODZIŃSKA K., SZAREK-ŁUKASZEWSKA G. 2003. Bryophytes. In: Markert B.A., Breure H.G., Zechmeister H.G. (Eds.), Bioindicators and Biomonitors. Elsevier Science Ltd., Amsterdam, pp. 329–375.

ZHONG Q., DU J., PUIGCORBÉ V., WANG J., WANG Q., DENG B., ZHANG F. 2019. Accumulation of natural and anthropogenic radionuclides in body profiles of Bryidae, a subgroup of mosses. Environmental Science and Pollution Research 26: 27872–27887. https://doi.org/10.1007/s11356-019-05993-3

ZHOU X., HU R., FANG Y. 2021. Source and spatial distribution of airborne heavy metal deposition studied using mosses as biomonitors in Yancheng, China. Environmental Science and Pollution Research 28: 30758-30773. https://doi.org/10.1007/s11356-021-12814-z

ZINICOVSCAIA I., HRAMCO C., CHALIGAVA O., YUSHIN N., GROZDOV D., VERGEL K., DUCA G. 2021. Accumulation of potentially toxic elements in mosses collected in the Republic of Moldova. Plants (Basel) 10, 3: 471. https://doi.org/10.3390/plants10030471