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Review

Do mosses exist outside of Europe? A biomonitoring reflection

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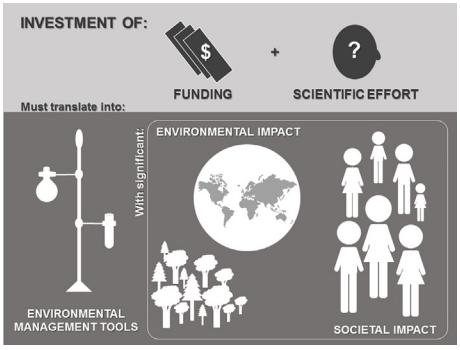
HIGHLIGHTS

- Environmental tools should be designed for their final exploitation in environmental monitoring, management and policy making
- Not being considered by governmental authorities for environmental monitoring may be indicative a low level of confidence
- Investment should focus on the improvement of these tools to encourage their application in environmental policy making

GRAPHICAL ABSTRACT



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ABSTRACT

The passive moss biomonitoring technique has been proved a useful environmental tool for the study of the air quality. However, after more than 40 years of its discovery, it has not been used yet in decision making when dealing with atmospheric pollution. Scientific efforts and funding are wasted when these sort of findings do not have a meaningful impact on society. Thus, the aim of this review is to showcase the reasons preventing the worldwide application of the moss technique. The results showed that the possible reasons underlying this problem are the lack of standardization of the technique, transmission of a false idea of robustness, and the lack of a theoretical background. Knowing and accepting these problems is the first step to encourage scientists and funding bodies to invest their efforts in really improving the technique for its application in environmental policies and not only in scientific circles.

Contents

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1. Introduction

Mosses are tiny non-vascular plants that belong to the second most diverse group of terrestrial plants (after angiosperms). They occur on all continents and grow on a wide range of substrates, such as soil, rock, bark, rotting wood, dung, animal carcasses and leaf cuticles. The only ecosystem that mosses (and bryophytes in general) have failed to colonize is the marine ecosystem (Vanderpoorten and Goffinet, 2009). The widespread presence of these organisms is illustrated by the fact that 93 European moss species (representing 7.2% of the total number of species known in Europe) are considered to be cosmopolitan, in other words, they are distributed worldwide (Dierssen, 2001). When considering moss genera (the classification ranking above species), this percentage is even higher and worldwide distributions are more or less the rule (Medina et al., 2011). The answer to the question about whether mosses exist outside of Europe is obvious - of course they do! However, if we take a look at the literature reporting studies in which the "moss technique" (the use of terrestrial mosses to monitor the atmospheric heavy metal inputs) has been applied, we see that 80% of the studies were carried out in Europe (the review was based on the information found in a total of 369 articles written between 1972 and 2014 and involving the passive biomonitoring of atmospheric heavy metals deposition with terrestrial mosses – see supplementary material from Fernández et al., 2015 for more information on the revised papers). The remaining 20% of the studies were carried out in America (9%), Asia (9%), the Polar Regions (3%) and Africa (1%). This raises a new question - why is the use of the moss technique mainly restricted to European countries?

Most of the articles consulted consistently report that terrestrial mosses are very valuable tools for assessing atmospheric levels of pollutants. However, outside of Europe this passive biomonitoring technique has not even been considered as a standard tool for air quality monitoring. Within Europe, the ICP Vegetation (International Cooperative Programme of Air Pollution on Natural Vegetation and Crops) was established in 1987 by the United Nation Economic Commission for Europe (UNECE) to study the impacts of heavy metal deposition and nitrogen on vegetation. Nonetheless, it was not until 2014 (more than 40 years after the moss technique was first used) that the European Committee for Standardization regulated the biomonitoring of air quality with terrestrial mosses (EN 16414, 2014). At this point, we must ask what is hampering the wider application of the technique. As mosses are distributed throughout the world, we can only imagine that it is a lack of financial resources that is preventing wider use of the technique. Logically, the better the economic performance and the higher the standard of living of a country, the greater the investment that could be made in environmental monitoring. We therefore related the Gross Domestic Product (GDP) of various countries (The World Bank IBRD-IDA, 2015) to the number of relevant articles (i.e. concerning application of the moss biomonitoring technique) published per country (Fig. 1). Scientific productivity in this field is highest in countries such as Norway, Poland, Germany and Finland, i.e. in northern Europe, where the moss technique originated. Conversely, countries with much higher GDP, such as the USA and Japan, show a very limited scientific productivity in this field. The following are three possible reasons explaining why important agencies such as the Environmental Protection Agency (EPA, USA) do not consider the moss technique a real option for air quality monitoring:

2. Lack of standardization of the moss technique

No scientifically-based protocol for carrying out the moss technique has yet been defined and routinely applied to monitor atmospheric pollution (Fernández et al., 2015). Development of technical aspects has taken second place to application of the method. This is obvious from the scant number of scientific studies aimed at improving or testing such aspects (Fig. 2). Thus, 56% of the studies reviewed focused on monitoring the air quality in a particular region. These are generally descriptive studies in which the concentrations are mapped and multivariate

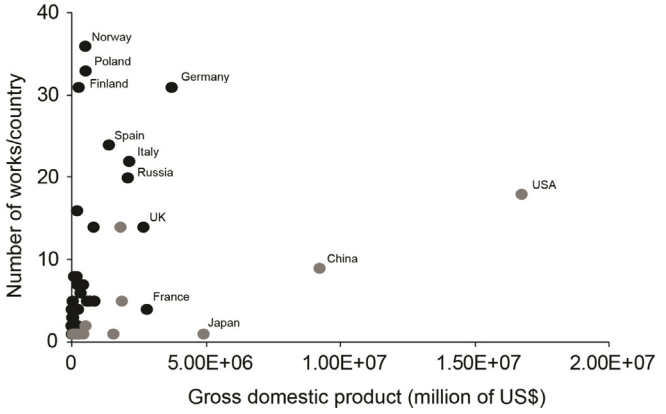

Fig. 1. Gross Domestic Product (GDP) (millions of US dollars) against the number of relevant articles (concerning the application of the moss technique) published per country. Black circles: European countries; grey circles: non-European countries.

analysis is applied (18% of all studies) without any hypothesis being tested. Only 31% of the studies reviewed attempted to assess how the technical aspects involved in applying the method affect the results obtained. Such aspects include the effect of soil or substrate on the concentrations of elements in moss tissues (6% of the studies), pre-sampling aspects such as the sampling design (2%) and interspecies comparisons (5%), sampling aspects such as the effects of vegetation (2%) and altitude (2%) on the concentrations, the representativeness of the sampling site (2%), and finally post-sampling aspects such as the analytical techniques used (3%). Descriptive studies are published in indexed journals of high impact, even though many of the journals claim to exclude such articles from their scope (e.g. they exclude "reporting the environmental analysis and monitoring of specific geographic areas without presenting new insights and/or hypothesis testing" and "describing results from routine surveys and monitoring programs that are primarily of local interest"). This has occurred of the course of many years (see Fig. 2). The lack of studies involving technical aspects can also be partly explained by the fact that many authors have used the method in one or two studies but it is not their main line of research (653 authors, i.e. 86% of all authors included in the review). Very few authors have published more than 10 articles in this field (11 of 763 authors).

3. Transmission of a false idea of the robustness of the technique

Articles on this topic consistently maintain that mosses are good monitors of atmospheric deposition. However, this is not necessarily true (Aboal et al., 2010; Boquete et al., 2015), as significant correlations

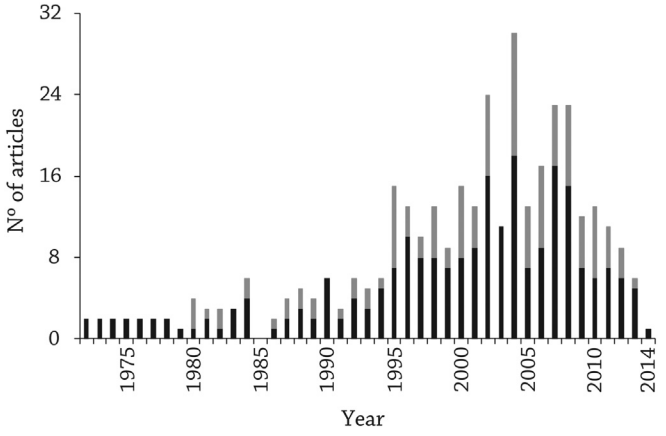

Fig. 2. Number of papers concerning passive biomonitoring of trace elements deposition with mosses (black bars) compared with the number of papers addressing technical aspects of the method (grey bars) each year between 1972 and 2014.