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Review

Inland water quality monitoring with native bryophytes: A methodological review

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ABSTRACT

Aquatic bryophytes are used as a simple, reliable and economic tool for passive biomonitoring of water quality. However, a harmonized protocol that would enable use of the method outside of the scientific field is not yet available. The aim of this literature review, which considers 73 articles published between 1979 and 2013, is to ascertain the current status of the technique and to evaluate the degree of standardization of each aspect of the method. The use of this tool is largely limited to Europe (80% of the articles reviewed). It has mainly been used to biomonitor inorganic (in 97% of the articles) and to a lesser extent organic contaminants (in 4% of the articles; note that the sum is greater than 100% because both inorganic and organic contaminants were studied in some studies). Methodological aspects were only considered in 15% of the articles. Moreover, 81% of the authors have only published one article on the topic and many different protocols have been used. As a result, the technique is not standardized, which hampers comparison of the results of different studies. Finally, we propose a protocol that would facilitate the use of the technique as a routine tool for monitoring the quality of inland waters.

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1. Introduction

Urban, industrial and energetic development in the past few decades has led to an increase in the pressures to which inland waters are subjected, e.g. from chemical contamination, physical degradation and overexploitation. As a result, the ecological status and chemical quality of inland waters have become seriously deteriorated (European Parliament and of the Council, 2003).

The legislative measures that have gradually been adopted to avoid such pressures and the associated environmental and ecological risks have helped alleviate this situation. In the European Union, the Water Framework Directive (2000/60/CE) established for the first time a strategy for the global protection of community waters that includes quality control standards and monitoring measures. Although biological and hydromorphological measures are taken into account for integrated diagnosis of contamination, the most common method of monitoring chemical contamination is still the direct measurement of the concentrations of contaminants in the water. However, the data thus obtained only reflect the concentrations of contaminants at the time of sampling, and episodic or intermittent contamination events may be overlooked (Greenwood and Roig, 2006).

New tools for the routine monitoring of water bodies must be developed and validated and existing methods must be improved. Detection of bio-available metals in water using non-biological accumulators (e.g. Diffusive Gradients in Thin film) has been recently studied (Diviš et al., 2007, 2012) and different organisms (e.g. bryophytes, algae, mussels) have been used as biomonitors of contamination for decades (Burton and Peterson, 1979; Kelly and Whitton, 1989; Mersch and Johansson, 1993). In the current review, we apply the term 'bryomonitoring' in the context of biomonitoring and the underlying organisms (i.e. bryophytes) by which environmental quality is determined. Aquatic bryophytes that grow at particular sites (i.e. native bryophytes) constitute a simple, reliable and economic tool of 'bryomonitoring' the surrounding environment (passive 'bryomonitoring'). This technique allows the detection of intermittent or sporadic contamination (Say et al., 1981) and the precise location of contamination sources (Mouvet et al., 1986). It is successful because of the anatomical and physiological characteristics of these plants, their specific kinetics of contaminant bioconcentration (Carballeira and López, 1997) and their permanent presence in the environment. The technique also enables the simultaneous monitoring of a large number of contaminants (inorganic and organic) by the analysis of a single sample, and it enables the evaluation of water quality both large scale (e.g. regional) and small scale (e.g. in the surroundings of possible contamination sources). Furthermore, this technique can be used to implement 'bryomonitoring' networks and Environmental Specimen Banks, allowing the combination of collection and storage of biota for real-time monitoring, retrospective monitoring and ecotoxicological research (e.g. Cesa et al., 2013 in Veneto—Italy and Vázquez et al., 2007 in Galicia—Spain). Despite the advantages of the technique, its use has been limited to scientific research, and although French water agencies collects and analyzes aquatic bryophytes at the same time as the water samples (www.eau-adour-garonne.fr), the technique has not been officially used by public authorities to evaluate the contamination of water bodies. This is mainly due of the lack of a well-established methodology and also because it is required broader understanding of the processes involved in metal uptake. A detailed discussion of this last aspect would be indicated for a future review on active 'bryomonitoring' (by transplanted bryophytes) of inland waters, this methodological review is also necessary because it is especially useful in areas where the presence of native bryophytes is limited or absent. Moreover, transplants can be used more conveniently for detect short time contamination peaks (e.g. in case of environmental emergencies) because initial concentration and exposure period are known, while the concentrations in native bryophytes represent the contamination corresponding to a particular site, without taking the temporal variability into account.

Nowadays, the only close reference to the application of this type of tool is the use of native terrestrial bryophytes to monitor atmospheric contamination. Terrestrial bryophytes have been used in Europe since 1990 as part of an international program investigating the effects of atmospheric contamination on the environment (http://icpvegetation.ceh.ac.uk/) and which includes a dense biomonitoring network of more than 6000 sampling sites (SS) distributed across 28 participating countries. The program provides data on the concentrations of twelve elements (i.e. Al, As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, Sb, V and Zn) in naturally growing mosses (Harmens et al., 2004).

In this literature review, after a brief description of the current state of the methodology, we will evaluate the degree of standardization of each of the stages involved in freshwater passive 'bryomonitoring' (i.e. sampling design, sample collection and sample preparation/processing) and we will identify those aspects that require further research. Finally, we propose a protocol that would enable the routine use of this tool for environmental monitoring. For this purpose, the technique should be: (i) easy to use, (ii) capable of indicating the presence of contaminants, (iii) capable of detecting as many contaminants as possible with maximal efficiency, and (iv) highly replicable.

2. Current trends in passive biomonitoring of inland water

This literature review includes 73 articles concerning the passive biomonitoring of inland water. The articles were all published between 1979 and 2013 and were located by using the SciVerse SCOPUS online tool. We selected articles that quantified the concentrations of contaminants in native bryophytes at particular sites, as well as those involving experiments related to methodological aspects.

On the one hand, 81% of authors have only published one article on the topic (Fig. 1). And of the large number of protocols reported, many have only been used on one occasion or only by the same group of researchers. Moreover, some articles provide little or no information about the techniques used (e.g. Smith, 1986; Callahan et al., 1994; Frank et al., 2004). On the other hand, the main aim of most of the articles revised (85%) was to biomonitor contamination (Fig. 2), and while those articles aiming at establishing a harmonized method by the study of particular aspects of the method were much less abundant (15%). In fact, only eight of the authors have published more than two articles and only three of them have researched some aspect of the methodology (e.g. Wehr et al., 1983; Kelly and Whitton, 1989; Carballeira and López, 1997). As a result, the technique has not yet been harmonized, which

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