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Monitoring temporal trends of air pollution in an urban area using mosses and lichens as biomonitors

Renato Gerdol [a,*], Roberta Marchesini [a], Paola Iacumin [b], Lisa Brancaleoni [c]

[a] Department of Life Sciences and Biotechnology, University of Ferrara, Corso Ercole I d'Este 32, I-44121 Ferrara, Italy
[b] Department of Physics and Earth Sciences, University of Parma, Parco Area delle Scienze 7/A, I-43124 Parma, Italy
[c] Botanical Garden, University of Ferrara, Corso Porta Mare 2, I-44121 Ferrara, Italy

HIGHLIGHTS

- Monitoring temporal trends of air quality is a major task in applied ecology.
- We used an integrated approach for biomonitoring air quality at five-year interval.
- We found contrasting trends of lichen diversity and metal accumulation in mosses.
- ^{15}N content in moss tissues indicated higher contribution of oxidized N species.
- In conclusion, the importance of different pollution sources changed over time.

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ABSTRACT

Monitoring air quality by using living organisms as biomonitors has received increasing attention in recent years. However, rather few studies were based on the concomitant use of passive biomonitoring (based on the different sensitivity of living organisms to air pollution) and active biomonitoring (based on their capacity to accumulate pollutants in the tissues). We carried out a repeated survey of an urban area in Northern Italy, with the objective of comparing temporal trends of different kinds of air pollutants with bioindication (passive biomonitoring) and bioaccumulation (active biomonitoring) techniques. During a five-year interval, temporal patterns of moss metal concentrations underwent significant changes probably due to intercurring variations in the importance of different pollution sources. Nitrogen (N) concentration in moss tissues also decreased and was paralleled by increasing diversity of epiphytic lichens. Increasing δ^{15}N in moss tissues suggested a higher contribution of oxidized N species compared with reduced N species.

1. Introduction

Atmospheric chemistry has strongly changed since the industrial revolution as an effect of human impact (Seinfeld and Pandis, 2006). Consequently, atmospheric pollution in urban and industrial areas represents a major concern because of its negative effects on human health and the environment. Monitoring air quality is complex due to several reasons such as the large number of potentially dangerous substances, the temporal and spatial variations in the input rates of different pollutants and the high costs of analytic instrumentations (Boubel et al., 1994; Tørseth et al., 2012). Therefore, increasing attention has been devoted in the last decades to biomonitoring of air quality. Biomonitoring techniques use living organisms either passively, based on the different sensitivity of living organisms to air pollution or actively, through their capacity to accumulate pollutants in the tissues (Falla et al., 2000; Wolterbeek, 2002). Epiphytic lichens are the by far most frequently used organisms for passive monitoring of air quality (Falla et al., 2000). On the other hand, several organisms have been employed as bioaccumulators of airborne pollutants: vascular plants (Malizia et al., 2012), lichens (Conti and Cecchetti, 2001) and mosses (Onianwa, 2001). Mosses, thanks to their morphological and physiological features show a high ability to accumulate airborne pollutants, especially trace metals (Schröder et al., 2008), but also organic compounds (Harmens et al., 2013a). Furthermore, some moss species form extensive populations which makes them suitable for monitoring air quality on large geographic scale (Holy et al., 2009; Schröder et al., 2010; Harmens et al., 2010, 2011, 2012).

* Corresponding author. Tel.: +39 (0)532 293775; fax: +39 (0)532 208561.
E-mail address: renato.gerdol@unife.it (R. Gerdol).

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Repeated surveys of a given area using biomonitoring techniques can reveal temporal trends of air quality. For example, several studies have reported lichen recolonization in urban areas that were totally depleted of epiphytic lichens until the Seventies (Rose and Hawksworth, 1981; Letrouit-Galinou et al., 1992; Isocrono et al., 2007; Lisowska, 2011; Kirschbaum et al., 2012). Recolonization of the so-called 'lichen desert' (Pearson and Skye, 1965) is clearly related to reduced SO_2 emissions all over Europe (Berglen et al., 2007). However, such improvement of air quality in terms of lower SO_2 emission is partly counteracted by a general increase in atmospheric nitrogen (N) deposition rates (Galloway et al., 2008). On the other hand, N concentrations in mosses are positively related to atmospheric N deposition rates (Solga et al., 2006; Harmens et al., 2011). Measurements of ^{15}N natural abundance in moss tissues document varying levels of reduced vs. oxidized N forms deriving from different emission sources (Baum et al., 2001; Dore et al., 2008; Zechmeister et al., 2008; Šakalys et al., 2009; Varela et al., 2013). Large-scale surveys of trace metal accumulation in moss tissue have shown a general decrease over time in Europe. However, such trend varies to a certain extent among elements, with the highest decline being documented for Cd, Pb and Hg and the lowest decline for Cr (Harmens et al., 2013b). Further variation in moss element accumulation may arise in relation to geographic scale and/or local temporal dynamics so that small-scale trends of trace metal concentration in moss tissue are strongly affected by local pollution sources and/or site-specific environmental factors (Schröder et al., 2008, 2010; Tørseth et al., 2012).

Recent studies have investigated if different species within broad taxonomic groupings behave consistently with respect to accumulation of pollutants or to their response to air-quality changes. For example, Solga and Frahm (2006) observed different abilities to accumulate N by six moss species subjected to experimental fertilization and Castello (2007) observed species-specific differences in the ability of two mosses to accumulate trace metals in their tissues. Hence, different moss species cannot always be interchanged for assessing atmospheric deposition levels. On the other hand, epiphytic lichens do not respond consistently to atmospheric N deposition. In particular, increasing N deposition rates may have slight effects on lichen abundance but may enhance the abundance of nitrophilic species at the expense of acidophilic species (van Herk, 2001; Gombert et al., 2003; Llop et al., 2012). Rather few studies have compared temporal and spatial trends of different kinds of air pollutants with bioindication (passive) and bioaccumulation (active) techniques. There seems to exist a general negative correlation between lichen abundance and trace metal concentrations in mosses and/or lichens. However, the specific patterns can vary greatly depending on the contribution of different pollution sources such as contaminated soils, plant emissions, domestic heating and vehicle traffic (Loppi and Corsini, 2003; Achotegui-Castells et al., 2013; Behxhet et al., 2013; Paoli et al., 2013). In this paper we present the results of a biomonitoring study based on an integrated approach in an urban area in Northern Italy. We monitored changes of air quality at a 5-year interval by comparing data of lichen abundance with data of N and trace metal accumulation in moss tissue. Our objective was to assess if the combination of the two techniques could provide reliable information about spatial and temporal trends of air pollution in this area.

2. Materials and methods

2.1. Study area and sampling design

The study was carried out in the municipality of Ferrara, Northern Italy, a city with a population of 132 000 inhabitants (44°49′ N, 11°37′ E; 10 m above sea level; Fig. 1a). The climate is temperate sub-continental with a mean annual temperature of 13.2 °C and a mean annual rainfall of 650 mm. The prevailing winds are westerly. Secondary wind directions are from NE and SE (Fig. 1b). Ferrara lies in the Po Plane, one of the most densely populated regions in Europe. The main sources of pollution in the Ferrara municipality are located in an industrial area that hosts many facilities, especially chemical plants. Pollutants are also released by point sources, such as car repair and paint shops, domestic heating plants, agricultural practices and vehicle traffic, both in the local road network and a motorway located rather close to the city center (Fig. 1c). However, the mean air concentrations of pollutants measured by the local environmental agency in 2011 (http://www.arpa.emr.it/cms3/documenti/_cerca_doc/aria/report_aria2012.pdf) were all within legal limits: NO_2 (35 μg m^{-3} yearly average, 40 μg m^{-3} legal limit); PM10 (35 μg m^{-3} yearly average; 40 μg m^{-3} legal limit); benzene (1.5 μg m^{-3} yearly average, 5 μg m^{-3} legal limit); CO (<0.6 mg m^{-3} yearly average, 10 mg m^{-3} legal limit); SO_2 (<14 μg m^{-3} yearly average, 20 μg m^{-3} legal limit).

The sampling was carried out in a 10 × 10 km area following the guidelines of ANPA (2001). The area was divided into 100 1 × 1 km squares (4 of them were located in the Po River bed and could obviously not be used for sampling; Fig. 1c). Whenever possible, mosses and/or lichens were sampled in a 250 × 250 m area (henceforth called sampling site) in all squares as detailed below. The squares were then grouped into the following four sectors, based on the distribution of CORINE land cover classes (European Environment Agency, 2007): the industrial sector (almost totally covered by CORINE class 1.2, 'Industrial, commercial and transport units'); the eastern residential sector lying downwind to the prevailing westerly winds (CORINE class 1.1, 'Urban fabric', mostly 'Continuous urban fabric' in the city centre and 'Discontinuous urban fabric' outside); the south-western agricultural sector lying downwind to the north-easterly winds (almost totally covered by 'Arable land', CORINE class 2.1 and 'Permanent crops', CORINE class 2.2) and the north-western mixed sector (partly covered by permanent crops but hosting some industrial units: a former waste dump and a large photovoltaic plant), lying downwind to the south-easterly winds (Fig. 1c).

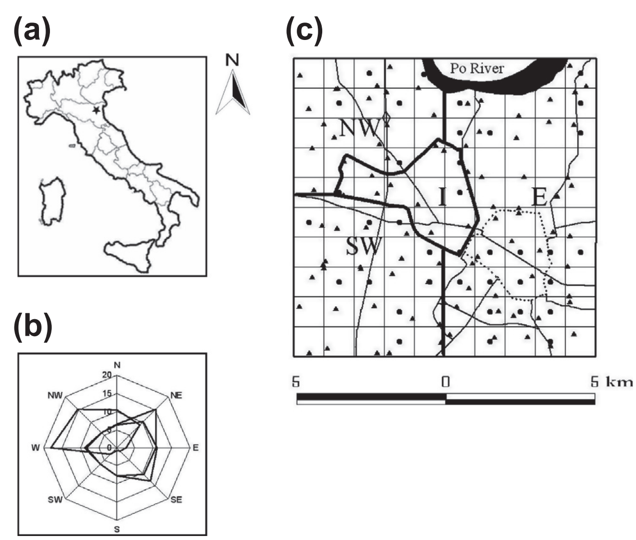

Fig. 1. Geographic location of the study area in Italy (a), wind directions (b) and detail of the area (c), with the 1 × 1 km raster superimposed. The sampling area was divided into four sectors based on the distribution of CORINE land cover classes: industrial (I), eastern (E), south-western (SW) and north-western (NW). The triangles indicate the location of the sampling sites for mosses, the dots indicate the location of the sampling sites for lichens. The dotted line limits the city centre. The continuous lines indicate main roads.