Ecological Indicators 52 (2015) 362–370

Contents lists available at ScienceDirect

Ecological Indicators

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

Lichens as suitable indicators of the biological effects of atmospheric pollutants around a municipal solid waste incinerator (S Italy)

Luca Paoli[a,*], Silvana Munzi[b], Anna Guttová[c], Dušan Senko[c], Giovanni Sardella[d], Stefano Loppi[a]

[a] Department of Life Sciences, University of Siena, Via Mattioli 4, 53100 Siena, Italy
[b] Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, Bloco C2, 1749-016 Lisbon, Portugal
[c] Institute of Botany, Slovak Academy of Sciences, Dúbravská cesta 9, 84523 Bratislava, Slovakia
[d] Regional Agency for Environmental Protection – ARPA Molise, Via Petrella 1, 86100 Campobasso, Italy

ARTICLE INFO

Article history:
Received 7 July 2014
Received in revised form
13 December 2014
Accepted 15 December 2014

Keywords:
Evernia prunastri
Functional groups
Lichen diversity
Mercury
Physiological parameters
Soil
Transplants

ABSTRACT

A comprehensive biomonitoring programme should integrate several methods distributed along the biomonitoring chain, allowing to detect exposure, threads and impacts. In the case of a municipal solid waste incinerator (MSWI), biomonitoring of air pollution can contribute to source attribution, detection of ongoing processes and assessment of environmental effects. Three different methods were used to assess the biological effects of air pollution around a MSWI using lichens as biomonitors: (1) lichen diversity; (2) bioaccumulation of trace elements; and (3) physiological status (photosynthetic efficiency, cell membrane damage, viability). The first method takes into account the native lichen flora, while the other two were applied to thalli of the lichen *Evernia prunastri* transplanted for 6 months in the study area. Lichen diversity and physiological parameters reflected the effects of air pollution around the incinerator and the surrounding industrial area. High frequencies of non-nitrophilous species corresponded to sites with higher environmental quality, while high frequencies of nitrophilous species corresponded to sites with higher level of eutrophication. Transplanted samples showed increased cell membrane damage and reduced vitality respect to control samples. Bioaccumulation of trace elements pointed at the atmospheric origin of Hg depositions in the area. These results suggest that an integrated use of lichen-based methods along the biomonitoring chain can provide useful biological outputs for decision-makers to establish correct sustainable waste management policies.

1. Introduction

Solid waste incinerators are still widely used worldwide as part of the waste management strategy, although their possible adverse effects are now well-known, and there is a high public concern in terms of both environmental and health consequences (Porta et al., 2009). Incinerators are potential sources of heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-*p*-dioxins (PCDDs) and dibenzofurans (PCDFs) that may contaminate air, soil, water and the biota. In this scenario, reliable and regular environmental monitoring of the emissions and of the biological effects connected with the release of airborne pollutants should be included in any process of ecological impact assessment in support of regulatory procedures (Treweek, 1999), also concerning waste management activities.

Biomonitoring of air pollution can contribute to the implementation of environmental policy on air quality and atmospheric pollution control, providing consistent data for environmental management (Pirintsos and Loppi, 2008). The use of lichens as bioindicators provides a special viewpoint on the atmospheric environment (Nimis et al., 2002) and different bioindication methods are available based on their specific response. Measuring the accumulation of airborne pollutants in lichen thalli can be used to assess spatial and temporal deposition patterns (e.g., of heavy metals). Biological responses can be used to estimate the extent of any effects: measuring physiological responses can serve as an early warning system of higher level effects and changes in species composition or in biodiversity provide a useful method for monitoring the status of an ecosystem and the impacts of emissions (Bealey et al., 2008).

* Corresponding author. Tel.: +39 0577235408; fax: +39 0577232896.
E-mail address: paoli4@unisi.it (L. Paoli).

http://dx.doi.org/10.1016/j.ecolind.2014.12.018
1470-160X/

Biomonitoring networks should have a suitable temporal and spatial framework, since biomonitoring relies on the ability to distinguish the pollutant signal from background levels and noise from other sources (Bealey et al., 2008).

Therefore, a comprehensive biomonitoring programme should integrate several methods distributed along the biomonitoring chain (Sutton et al., 2005), allowing to detect exposure, threads and impacts. In this framework, among the available methods, measurements with a stronger link to source attribution (e.g., bioaccumulation) are helpful to detect exposure and threads, but have a weaker link to the environmental effects, whereas methods indicating the effects on the environment or human health (i.e., responses at species or community level) show a close link to the selected features of interest, but a weaker link to source attribution (see Markert et al., 2003; Sutton et al., 2005).

Hence, biomonitoring with lichens allows detecting changes in the flora, variations in lichen trace element content and physiological status, providing useful evidence for spatial and temporal trends in ambient pollution burdens (Loppi, 2014). Lichen metabolism depends on the mineral uptake from the atmosphere, therefore these organisms are effective in trapping trace elements from the surrounding environment and it has been demonstrated that the concentrations of trace elements in lichen thalli are directly correlated with the environmental levels of these elements (Bari et al., 2001; Sloof, 1995). With the transplant technique, healthy lichen thalli are taken from a relatively clean site, transplanted to the study sites and their responses are recorded. In this new environment, if properly exposed, lichens will accumulate airborne chemicals and adapt their metabolism mainly according to the impact of pollution and not because of the transplantation itself (Garty et al., 1993). For these reasons, lichen monitoring can be used as a complementary system that integrates instrumental monitoring of air pollution.

Case-studies connected to waste management showed that lichens reflect the deposition of trace elements around waste incineration facilities (e.g. Loppi et al., 2000; Tretiach et al., 2011), cement mills powered by waste combustion (e.g. Ljubič Mlakar et al., 2011), solid waste landfills (e.g. Paoli et al., 2012). In particular, lichens well reflect the spatial and temporal impact of Hg pollution originating from waste incineration (Ljubič Mlakar et al., 2011; Tretiach et al., 2011).

In this paper, we used three methods to investigate the biological effects of air pollution around a MSWI in S Italy. Using lichen diversity indices as a long-term indicators of the environmental conditions we aimed to test whether nitrophilous species diffuse and oligotrophic retreat in and around the industrial area concerned by the presence of the MSWI. Using transplants of the lichen *Evernia prunastri* we aimed to test whether (1) Hg and other heavy metal depositions are of airborne origin; and (2) ongoing processes induce early signs of physiological stress in the transplants.

2. Materials and methods

2.1. Study area

The study area (Fig. 1) is located in the inner part of the region Molise (Italy) and lies along the alluvial plain of the river Volturno, bordered by two hilly chains running from NE to SW. Elevation ranges from 200 m in the lowland up to 900 m in the surrounding hilly areas. The climate is temperate sub-continental, with mean annual temperature in the range 10–14 °C and precipitation over 700 mm. Prevailing winds blow from N–NE and SW. Four protected sites, belonging to the Natura 2000 network, surround and partially overlap the study area.

Industrial activities, consisting of ca. 30 enterprises, including manufacturing and processing of metals, chemicals, plastics, electronics, agri-food stuff and a municipal solid waste incinerator (MSWI) combined with an electric power plant for energy generation from waste burning (operating since 2009 after revamping) are present in the study area. Measurements are available for some airborne pollutants referring to the period of lichen exposure (see further): NO_2 8–26 $\mu g/Nm^3$, SO_2 0.1–1.4 $\mu g/Nm^3$, PM_{10} 20–43 mg/Nm^3, NH_3 1–10 $\mu g/Nm^3$, As, Cd and Ni < 0.5 ng/Nm^3, Hg < 0.001 ng/Nm^3 (ARPA Molise, 2012).

2.2. Experimental design

The study area was divided into 26 sampling units (1 km^2 each) distributed as follows: (1) sampling units in the industrial area, including the MSWI (3 plots); (2) sampling units in rural sites of the lowland (12 plots); (3) sampling units in rural sites of the surrounding hills (6 plots); (4) forested (including Natura 2000) areas (5 plots). In each sampling unit we measured: (1) the diversity of epiphytic (tree inhabiting) lichens as indicator of air quality; (2) the content of selected trace elements of toxicological relevance bioaccumulated in thalli of the lichen *E. prunastri* taken from a remote site and exposed in the study area for 6 months; (3) selected physiological parameters of the exposed samples to assess their status after the transplantation.

2.3. Diversity of epiphytic lichens

The diversity of epiphytic lichens was measured by an Index of Lichen Diversity (ILD) according to a standard methodology (ANPA, 2001). The ILD was calculated as the sum of frequencies of epiphytic lichens in a sampling grid consisting of four $50 \times 10\, cm^2$ ladders, each divided into five $10 \times 10\, cm^2$ units. The grid was placed systematically on the N, E, S and W cardinal sides of the bole of each tree, 1 m above the ground. The ILD of each tree corresponded to the sum of frequencies of epiphytic lichens in the grid and the ILD of each monitoring site was the arithmetic mean of the ILD measured for each sampled tree (ANPA, 2001). Tree boles were deemed suitable if well lit, with girth >60 cm, trunk almost straight (inclination <20°), not damaged and with bryophytes covering less than 25%. Lichen sampling was made on deciduous oak trees (*Quercus pubescens* and *Q. cerris*) and in a few sites, where oak was not present, on *Olea europaea* trees (only trees not treated for oil production), since it has been shown that *Quercus* and *Olea* barks provide comparable lichen diversity values (Giordani et al., 2001). For each sampling unit, 3–12 trees have been sampled (ANPA, 2001). In case of identification problems during field sampling, specimens were collected and identified later in the laboratory. Nomenclature follows the on-line database *ITALIC* (Nimis and Martellos, 2008).

2.3.1. Data interpretation

Because eutrophicating and non-eutrophicating air pollutants have different effects on the occurrence of lichens (Loppi, 2004; VDI, 2005; Pinho et al., 2011), we accounted separately the diversity of species which respond positively to eutrophication (nitrophilous) and of species which respond negatively (oligotrophic). Therefore, following the suggestions of Loppi and Nascimbene (2010), for the interpretation of ILD values in terms of biological effects of air pollution, lichen frequencies were evaluated by grouping the species according to the functional traits of biodiversity in response to eutrophication (Loppi, 2004), in particular grouping nitrophilous species according to the classification of the lichens of Italy by Nimis and Martellos (2008). Species with maximum score 4 or 5 were considered as nitrophilous and used to calculate the ILD_{nitro} (Loppi, 2004). Species with maximum score 3 were considered as non-nitrophilous (oligotrophic) and used to calculate the ILD_{oligo}.