# LICHEN BIOMONITORING OF GEOTHERMAL AIR POLLUTION IN CENTRAL ITALY

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## ABSTRACT

Epiphytic lichens have bcen uscd as biomonitors of air pollution in the Travale-Radicondoli geothermal field (central Italy) Two different approaches have been used: bioindication of air quality and bioaccumulation of trace elements and radionuclides Bioindication showed the worst air quality to occur around the geothermal power plants, up to a distance of about 500 m, and proved to be a reliable fool in delimiting the effect of geothermal air pollution. Bioaccumulation showed a very low occurrence of toxic heavy metals such as Cd, Hg and Pb and relatively high values for Al, As, B, Co, Cr, Fe, Mn, Mo and Ni, but did not point out any clear relationship between the occurrence of trace elements and the presence of the geothermal power plants, the only exception being represented by boron The concentrations of radionuclides found at Travale-Radicondoli proved to be comparable or even lower than those found in control arcas.

## 1. INTRODUCTION

The use of living organisms as biomonitors for atmospheric pollution is based on the fact that they react to ecological changes caused by pollutants (Manning and Feder, 1980). In spite of their feeding almost exclusively dependent on the atmosphere and the lack of protective mechanisms against air pollutants, lichens have bcen widely used in biomonitoring of air pollution (for a recent review see Gasparo *et al.*, 1989).

Lichens are well known for their extreme sensitivity to gaseous pollutants and for their ability to accumulate many airborne substances to concentrations well above those in the environment (Terry *et al.*, 1973; Nieboer and Richardson, 1981). Because of these peculiarities, lichens have been used both as bioindicators of air quality and bioaccumulators of trace elements and radionuclides

Although lichens have somewhat been used as biomonitors of geothermal air pollution, taking particular account of the fallout of mercury (Bargagli and Barghigiani, 1991), boron (Koranda, 1980), radon (Matthews, 1981) and other metals (Connor, 1979) from geothermal emission, they have never been used systematically The present study was undertaken with the aim of performing a detailed biological monitnring by epiphytic lichens of the atmospheric pollution arising from geothermal installations.

## 2. STUDYAREA

The survey was performed in the Travale-Radicondoli geothcrmal field (central Italy), an area of ahout 15 km² located 22 km south-west of Siena and 15 km east of Larderello (Fig.1). This area was chosen since the only sources of air pollution are the geothermal installations, consisting of a 30 MW ("Radicondoli") and three 20 MW ("Pianacce". "Rancia-1" and "Rancia-2") power plants

The area is characterized by relatively gentle topographic undulations, with elevation ranging from 300 lo 560 m. The climate is humid sub-Mediterranean, over a range of 1000 mm for mean annual rainfall and 13°C for mean annual temperature (Barazzuoli *et al*, 1993) Prevailing winds are westerly. south-south-easterly and east-south-easterly (ENEL.unpublished data)

## 3. .MATERIALS AND METHODS

### 3.1 Bioindication

Fifty-one sampling stations were chosen through the study area (Fig.1) according to preferential sampling both because of the uneven distribution of suitable stations and the variations found between neighbouring localities. In each station the epiphytic lichen vegetation was sampled by the Index of Atmospheric Purity (IAP) method, which allows to express the richness of lichen vegetation with a single number, the IAP, according to which the higher the IAP the better the air quality (LeBlanc and De Sloover, 1970).

Sampling was performed on 1-5 isolated oak (*Quercus pubescens*) trees per station having a trunk circumference of not less than 70 cm, inclination not exceeding 10° and not showing signs of disturbance. IAP was calculated according to the standards suggested by Herzig and Urech (1991), which calibrated a standard IAP technique with a prediction of 98% against air pollution, by means of which it is possible to convert lichen data tu air quality values. These are as follows: (i) a 30x50 cm grid divided into 10 units of 10x15 cm was placed on the trunk of each tree at a height of 120-200 cm, on thr side of the bole with highest lichen density; (ii) all the lichen species were noted together with their frequency (F), namely the numher of grid units in which the species was present; (iii) IAP was calculated for each grid as ihe sum of the frequencies of all the species present (IAP=ΣF); (iiii) IAP for each station was taken as the maximum calculated within the station as to reflect the potential performance of the epiphytic lichen vegetation in each station

### 5.2 Bioaccumulation of Trace Elements

Lichen samples of a single species (*Parmelia caperata*) were collected in 33 stations for determination of trace elements accumulated in the thalli

Samples were air-dried, powdered, homogenized and about 150 mg of material was mineralized for 8 h with concentrated nitric. acid at 120°C (Stoeppler and Backhaus, 1978). Determinations were made by atomic absorption spectrophotometry, using the oxyacetylene flame for As, Cr, Cu, Fe, Mn, Mo, Ni, Sb and Zn, the graphite furnace for Al, Cd, Co and Pb and the cold vapor technique for Hg, and by inductively coupled plasma emission spectrometry for B and S. Trace element concentrations were expressed on a dry weight basis.

### 3.3 Bioaccumulation of Radionuclides

In 18 stations 5-10 thalli of *Parmelia caperata* were collected for determination of radionuclides. Since up to the present knowledge the methodology adopted in this study has never beeu applied to lichens, in order to allow comparison. collections have been made also in two contml areas (3 stations per area): Belforte, an area located close to the Travale-radicondoli field but nut subject tu geothcrmal exploitstion, nnd Chianti, a remote area of central Tuscany. Both control areas are similar to Travale-Radicondoli as to habitat and climatic regime and their lichen vegetation is luxuriant (IAP measurements in the sampled stations gave average values of 68±6 for Belforte and 72±8 for Chianti), Thalli were air-dried, stored in the oven at 110°C for 12 h and finally ashed at 400°C for 12 h (Bergamini *et al.*, 1969, 1979). For each sample, total β radioactivity was determined using a low-background detector with a counting efficiency of 42.3±0.5%. Results were expressed in $Bq \cdot g^{-1}$ dry weight.

## 4. RESULTS

### 4.1 Bioindication

IAP values ranged from a minimum of 0, recorded in the vicinity of the 'Radicondoli' power plant, to a maximum of 82, found in the south-west. The average IAP value for the whole area is 35 and the standard deviation is 20. The rather high coefficient of variation (57.1%) indicates that the 51 sampling sites do not all have similar levels of air pollution.
According to all the IAP values recorded, the average IAP value and the standard deviation, a zoning of the study area has been proposed into four air quality zones:

- Zone A: 0 ≤ IAP ≤ 25, high pollution;
- Zone B: 26 ≤ IAP ≤ 45, moderate pollution;
- Zone C: 46 ≤ IAP ≤ 65, low pollution;
- Zone D: IAP > 65, negligible pollution.

According to the two-dimensional map of air quality (Fig 1) obtained by the automatic mapping program SURFER (Golden Software Inc., Colorado), zone A is located into two belts, one in the surroundings of the 'Radicondoli' power plant and the other around the 'Pianacce', 'Rancia-1' and 'Rancia-2' power plants. Zone B is diffused from north to south, zone C mostly occupies a western belt and zone D occurs in a limited belt to the south-west.
At 'Pianacce', 'Rancia-1' and 'Rancia-2' the distribution of zone A is centred around the power plants but at 'Radicondoli' it is shifted north-north-easterly and this can be explained by the fact that the latter power plant is located on the top of a hill and by the resulting direction of the prevailing winds. However, the extent of zone A is limited to a maximum of about 500 m from the geothermal power plants.

### 4.2 Bioaccumulation of Trace Elements

Trace element concentrations found in *Parmelia caperata* are summarized in Table 1. By averaging the three lowest values recorded in the study area, for each element a background value was assessed (Nimis *et al.*, 1993), which proved to be consistent with the data reported for background areas by other authors who used lichen thalli of *Parmelia* species in similar studies. By comparing the mean concentrations with the background data, the Travale-Radicondoli area showed a very low occurrence of toxic heavy metals such as Cd, Hg and Pb and relatively high values for Al, As, B, Co, Cr, Fe, Mn, Mo and Ni. For some lithogene elements, namely Al, Co, Cr, Fe, Mn and Ni, it is likely an origin from soil and rock dust suspended by wind.
Correlation analysis showed highly significant correlations ($p<0.001$) for the following pairs of elements: Al-Fe, Al-Zn, Cd-Zn, Co-Mo, Co-Sb, Cr-Ni, Fe-Zn and Mo-Sb.
The distribution maps of the 16 trace elements did not show any influence of the geothermal installations except for B, whose pattern is the only one which seems to be affected by the power plants. The B content in lichen thalli proved to be significantly related ($r=-0.73$, $p<0.001$) to the distance from the power plants (Fig.2) and this further suggests that the geothermal installations constitute a major source of B pollution. Weaker, but nevertheless statistically significant trends were observed also for Al ($r=-0.43$, $p<0.05$), Cu ($r=-0.40$, $p<0.05$), Hg ($r=-0.39$, $p<0.05$), Mn ($r=-0.46$, $p<0.01$) and Zn ($r=-0.50$, $p<0.01$).

### 4.3 Bioaccumulation of Radionuclides

Concentrations of radionuclides found in *Parmelia caperata* in the study area were in the range 0.18-0.66 $Bq \cdot g^{-1}$ and no relationship with the power plants was evident. The average concentration is 0.51±0.12 $Bq \cdot g^{-1}$. The low coefficient of variation (23.6%) suggests that all the 18 sampling stations have similar levels of radionuclides. The concentrations of radionuclides found at Travale-Radicondoli proved to be comparable or even lower than those found in the

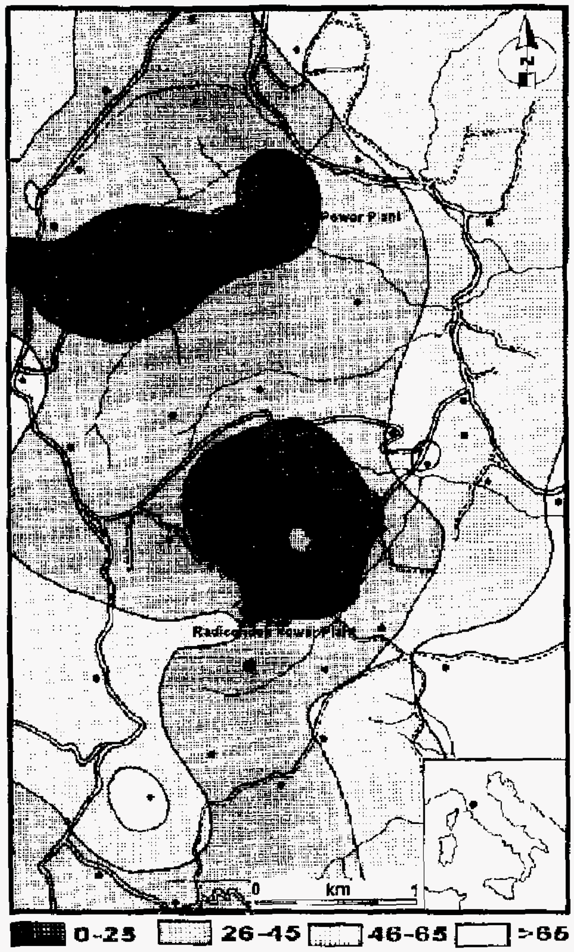


**Figure 1.** Two-dimensional map of air quality of the study area based on the IAP values (dots indicate the location of sampling sites)

Belforte and Chianti stations (0.52±0.04 and 1.05±0.21 $Bq \cdot g^{-1}$ respectively).

## 5. DISCUSSION

Apparently the results of the two biomonitoring approaches do not agree. On the one hand, lichen bioindication, which is based on an indirect approach (results on air quality are deduced from the response of the species), points out the geothermal power plants as the main source of atmospheric pollution in the studied area. On the other hand, lichen bioaccumulation, which is based on a direct approach, does not show any clear relationship of trace elements with the geothermal power plants, the only exception being represented by boron.
However, the results of the two approaches are reconcilable taking into account that generally the elements analyzed do not go with the steam but remain with the condensate. Furthermore, the re-injection of exhaust vapors to obtain high kinetic fluid determines the release of only a negligible fraction of non-condensable gases, i.e. most of the trace elements could be re-injected while non-condensable gases could be responsible for lichen injuries. In addition, although there are no primary data in the study to prove synergism among pollutants, it might be possible that the joint effect of some noxious pollutants (e.g. arsenic and mercury) could cause a detrimental effect on lichens, as already stated by Ammann *et al.* (1987).
The results agree both for IAP and boron, air pollution involving limited belts restricted up to a distance of about 500 m from the power plants. These results are in agreement with other studies which showed a sharp decrease in B and Hg concentrations in air, soil, mosses, lichens and tree leaves around Italian geothermal

Table 1. Kange (Min, Max), mean valuc (M), standard deviation (SD) ($\mu g \cdot g^{-1}$ dry weight) and coefficient of variation (CV%) of trace elements detected in *Parmelia caperata* thalli

| | Al | As | B | Cd | Co | Cr | Cu | Fe | Hg | Mn | Mo | Ni | Pb | S | Sb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min | 150 | 0.19 | 5.1 | 0.110 | 0.61 | 1.25 | 4.5 | 275 | 0.053 | 10.9 | 0.22 | 1.65 | 2.1 | 990 | 0151 | 22.2 |
| Max | 2750 | 3.55 | 25.4 | 0.691 | 1.99 | 8.41 | 25.4 | 2370 | 0.555 | 280.0 | 3.07 | 8.18 | 19.7 | 2860 | 0.825 | 66.1 |
| M | 969 | 1.19 | 12.3 | 0.329 | 1.15 | 4.51 | 10.8 | 1019 | 0.199 | 85.8 | 1.25 | 4.41 | 6.3 | 1541 | 0.433 | 43.0 |
| SD | 528 | 0.79 | 5.9 | 0.156 | 0.33 | 1.99 | 4.6 | 450 | 0.106 | 70.6 | 0.68 | 1.57 | 3.8 | 507 | 0.188 | 11.5 |
| CV % | 54.5 | 66.4 | 47.6 | 47.4 | 28.7 | 44.1 | 42.9 | 44.2 | 53.3 | 82.3 | 54.1 | 35.6 | 60.8 | 32.9 | 43.4 | 26.8 |

power plants (Verona, 1960; Breder and Flucht, 1984; Baldi, 1988; Bargagli and Barghigiani, 1991).

In the Travale-Radicondoli area it is likely that along with boron, $H_2S$ could be one of the main pollutants responsible for the decline of lichens around the geothermal installations.

As far as radionuclide pollution is concerned, the results of the present survey neither point out any relationship with the geothermal installations, nor show higher concentrations in the Travale-Radicondoli geothermal field with respect to control areas. These results are consistent with the findings of other authors, e.g. Matthews (1981) which showed that at Wairakei (New Zealand) the $^{210}Pb$ content of lichens collected in geothermal areas was not significantly higher than that of lichens in non-geothermal areas.

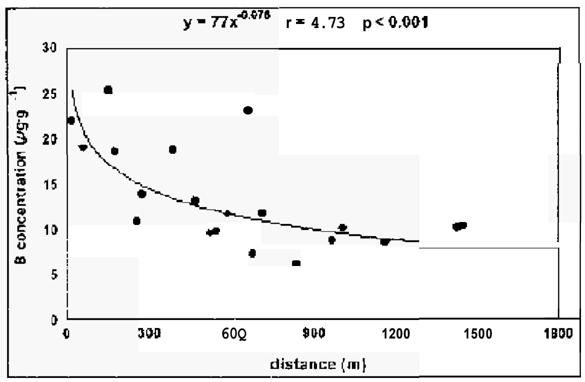


**Figure 2.** Relationship between the boron content of *Parmelia caperata* thalli and the distance from the power plants

## 6. CONCLUSIONS

From the present survey it is possible to conclude that lichens as bioindicators can serve as a reliable tool in delimiting the effect of geothermal air pollution and that at Travale-Radicondoli this effect extends up to about 500 m from the power plants. As far as lichen bioaccumulation is concerned, except for boron, the geothermal power plants neither seem to act as a point source of trace elements and radionuclides nor to pose immediate environmental problems with regard to metal and radionuclide pollution. In the study area the joint use of lichens as bioindicators of air quality and bioaccumulators of trace elements and radionuclides proved to be a powerful and inexpensive instrument to point out the most polluted areas and to outline the main pollutants.

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