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Environmental Pollution 116 (2002) 123–128

ENVIRONMENTAL POLLUTION

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Biodiversity of epiphytic lichens and air pollution in the town of Siena (Central Italy)

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Received 28 December 2000; accepted 2 April 2001

"Capsule": *Biodiversity of epiphytic lichens was used to demonstrate improvement of air quality in Siena, Italy*

Abstract

The results of a biomonitoring survey carried out in the town of Siena (central Italy) using the biodiversity of epiphytic lichens as indicator of air pollution are reported. The general picture was rather good, with more than 60% of the study area being in the categories "semi-natural" or "natural" according to a calibrated scale of environmental naturality/alteration. Compared with the situation of 1995, ameliorating conditions were found as a result of an improvement in air quality over time.

Keywords: Air pollution; Biodiversity; Italy; Lichens; Siena; SO_2; Urban environment

1. Introduction

Lichens are valuable biomonitors of atmospheric pollution. Unlike higher plants, they lack waxy cuticle and stomata and readily absorb gases and dissolved substances in the air through their surface (Hale, 1983). Correlations between high concentrations of sulphur dioxide in air and lichen decline is well documented (Seaward, 1993) and uptake of SO_2 by some lichen species was found to be linearly correlated with atmospheric concentration of this pollutant (Gries et al., 1997). Certain species are damaged or killed by yearly mean levels of SO_2 as low as 11 μg/m^3 (Bates et al., 1996). Other oxidizing compounds, such as nitrogen oxides, are also toxic to lichens (Sigal and Nash, 1983).

Lichen changes at community or population level are used as sensitive indicators of the biological effect of pollutants (Richardson, 1991) and the mapping of lichen diversity is becoming routine in several countries (Sigal, 1988; VDI, 1995; Canapini, 1999) since it provides an indication of the biological impact of air pollution. It is also quick and inexpensive and provides results on which predictions for human health can be based (Cislaghi and Nimis, 1997).

Lichen mapping is especially useful in urban areas, where the high density of different emitting sources makes monitoring of air pollution with detectors an extremely difficult task due to the variety of pollutants (Showman, 1988). There is also evidence that lichens can be used to monitor air quality changes in urban areas over intervals of a few years (Loppi et al., 1997).

This paper presents the results of a case study carried out in the town of Siena (central Italy) using the biodiversity of epiphytic lichens as indicator of air pollution. The aim of the study was to provide a general picture of the air pollution pattern within the study area and to look for changes since a study in 1995 by Monaci et al. (1997).

2. Materials and methods

The study was performed in the urban area of Siena (Fig. 1), where, inside the medieval town walls, the ancient narrow, winding streets have been conserved. The elevation of the town is between 300 and 350 m. Climate is sub-Mediterranean, with a mean annual temperature of 13.9°C and a mean annual rainfall of

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0269-7491/01/$ - see front matter
PII: S0269-7491(01)00151-8

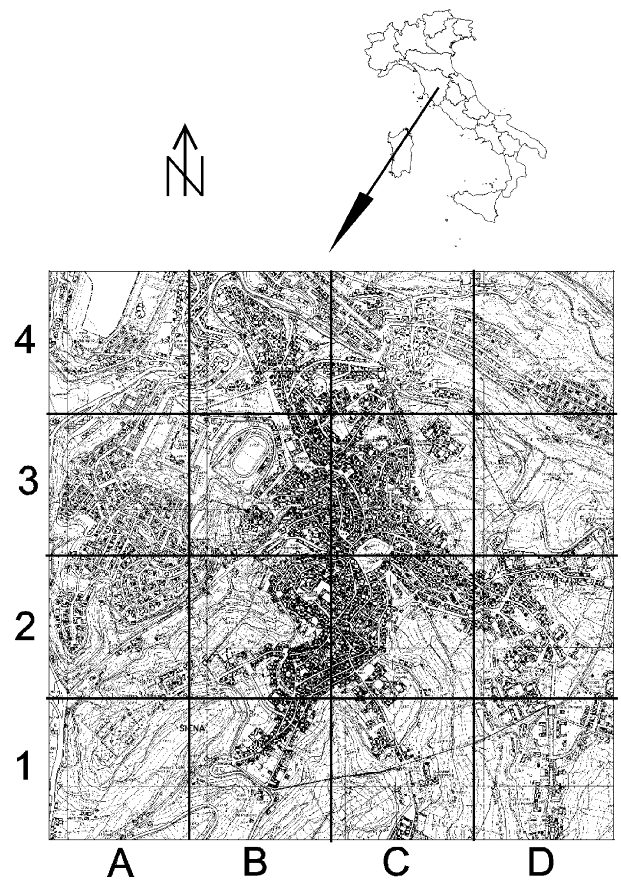

Fig. 1. Study area with the division into 16 operational geographical units (OGUs) of 500×500 m each.

813 mm, which is concentrated in autumn and winter, while summer is fairly dry; prevailing winds are northwesterly (Barazzuoli et al., 1993). Siena has a population of about 60,000 inhabitants and due to the prevalent touristic vocation of the town and the very limited industrial activity, vehicular traffic and domestic heating are the main sources of atmospheric pollution.

Due to its limited size (4 km^2), the study area was divided into 16 operational geographical units (OGUs) of 500×500 m each, following the wider network of 3×3 km already used for monitoring the effects of air pollution on forest ecosystems (European net EU-UN/ECE). In May–June 1999, 6–10 lime trees (*Tilia* sp.) were sampled in each OGU. Trees were deemed suitable if having a circumferences not less than 70 cm and inclination not exceeding 10°; damaged trees or those visibly affected by humans or animals were excluded.

Lichen sampling was based on a measure of biodiversity, calculated as the sum of the frequencies of epiphytic lichens in a sampling grid of 30×50 cm divided into 10 units of 15×10 cm. The bottom of this grid was placed at a height of 100–130 cm above ground, on the side of the trunk of each tree where lichen abundance was greatest. All the lichen species within the grid were noted together with their frequency (F), namely the number of grid units in which the species occurred. The sum of frequencies of all species was the lichen biodiversity (LB) of the tree. The LB of each OGU was calculated as the arithmetic mean of the LBs of the trees in the OGU; the accuracy of the estimate was examined by the standard deviation and the coefficient of variation.

In case of identification problems during field sampling, thalli were collected and identified in the laboratory. In the following cases, the nomenclature (Nimis, 2000) should be interpreted in a broad sense since diagnostic characters were not clear or problematical to detect in the field: *Lecanora carpinea — L. leptyrodes, Parmelia subrudecta — P. borreri, Parmotrema chinense — P. stuppeum, Physcia adscendens — P. tenella.*

A two-dimensional zone-map was drawn using the plotting program SURFER (Golden Software Inc., Colorado), which transforms discrete data into a continuous distributional model, using kriging (geostatic autocorrelation of the nearest randomly placed value to produce an estimate of minimum least squares variance) as interpolation algorithm (Olea, 1974). To insert the data into the program, the geographical coordinates of the centre of each OGU were used.

3. Results and discussion

A total of 57 lichen species were found on the 114 lime trees examined in the study area (Table 1). Compared with other towns in Tuscany (Loppi and Corsini, 1995; Loppi et al., 1996a, 1996b, 1996c), Siena has a fairly rich lichen flora. The genus with the highest number of species was *Parmelia* (10 species). The commonest species, present in all OGUS, were *Physcia adscendens*, *Hyperphyscia adglutinata*, *Parmelia subrudecta* and *Xanthoria parietina*; another three species, *Physconia grisea*, *Lecidella elaeochroma* and *Candelariella xanthostigma*, were present in all OGUs but one. In general, the lichen vegetation was a mixture of *Xanthorion* and *Parmelion* synusiae.

Lichen biodiversity counts can be taken as estimates of environmental quality: high values correspond to good situations while low values indicate poor quality. Such measures are chiefly depending from the two main reactions of epiphytic lichen communities to air pollution by phytotoxic gases, especially SO_2 and NO_X: a decrease in the number of species and in their cover/frequency (Nimis, 1999). The LB values measured in the present study were in the range 10–111. Mean LB values in the OGUs ranged from 33±11.2 to 86.1±12.9; the coefficient of variation ranged from 11.4 to 47.7%, indicating rather homogeneous conditions within the OGUs. The mean LB value for the study area was 56.5±24.1; the overall coefficient of variation was rather high

Table 1
Lichen species found in the study area[a]

	OGUs	Trees	*F*
Physcia adscendens	16	99	8.6
Hyperphyscia adglutinata	16	86	8.7
Parmelia subrudecta	16	80	5.1
Xanthoria parietina	16	52	3.3
Physconia grisea	15	76	7.7
Lecidella elaeochroma	15	63	5.8
Candelariella xanthostigma	15	61	4.8
Lepraria sp.	14	69	6.9
Parmelia tiliacea	14	56	4.3
Candelaria concolor	14	55	6.2
Parmelia subaurifera	13	49	5.7
Parmelia sulcata	13	47	4.1
Lecanora chlarotera	13	34	3.4
Physcia biziana	13	23	2.4
Phaeophyscia orbicularis	11	26	5.5
Phaeophyscia chloantha	11	23	5.3
Evernia prunastri	10	26	3.0
Amandinea punctata	10	24	5.6
Parmotrema chinense	10	22	1.9
Phaeophyscia hirsuta	10	15	4.0
Parmelia caperata	8	41	5.2
Lecanora horiza	7	14	4.1
Mycomicrothelia confusa	4	7	8.9
Lecanora carpinea	4	6	2.2
Parmelia exasperatula	4	6	2.0
Arthonia radiata	4	5	1.8
Hypogymnia tubulosa	4	5	1.4
Candelariella reflexa	3	5	3.6
Parmelia acetabulum	3	4	1.3
Physconia distorta	3	3	4.7
Pertusaria albescens	3	3	2.0
Physconia perisidiosa	2	9	6.9
Rinodina sophodes	2	6	4.0
Ramalina fastigiata	2	3	1.0
Leprocaulon microscopicum	2	2	4.5
Physcia aipolia	2	2	1.5
Caloplaca cerina	2	2	1.0
Parmelia exasperata	2	2	1.0
Ramalina farinacea	2	2	1.0
Caloplaca cerinella	1	4	6.5
Hypogymnia physodes	1	2	8.0
Parmelia quercina	1	1	5.0
Arthonia patellulata	1	1	3.0
Parmelia elengatula	1	1	3.0
Caloplaca ferruginea	1	1	2.0
Candelariella vitellina	1	1	2.0
Physconia servitii	1	1	2.0
Anaptychia ciliaris	1	1	1.0
Anisomeridium sp.	1	1	1.0
Arthrosporum populorum	1	1	1.0
Diploicia canescens	1	1	1.0
Lecanora allophana	1	1	1.0
Normandina pulchella	1	1	1.0
Opegrapha atra	1	1	1.0
Phlyctis argena	1	1	1.0
Physcia stellaris	1	1	1.0
Usnea sp.	1	1	1.0

[a] OGUs = number of OGUs where the species was found, $n=16$; Trees = number of trees on which the species was found, $n=114$; F = mean frequency of the species on trees hosting it.

(42.7%), indicating fairly heterogeneous LB values across OGUs.

Biomonitoring techniques assess the deviations from natural conditions of pollution-reactive components of the ecosystems, and it is therefore of crucial importance to quantify "naturality" in different situations (Nimis, 1999; Nimis et al., 2000). As the conditions for lichen growth vary from region to region, to ensure comparability, geographical patterns of LB values should be interpreted according to specific regional scales which group LB values into classes, according to their deviation from "natural" conditions (Loppi et al., 2001a). The isopleth map of LB values is shown in Fig. 2. The LB values were interpreted in terms of deviations from natural conditions (Table 2), using a scale of environmental naturality/alteration calibrated for trees on the Tyrrhenian side of Italy (Loppi et al., 2000b).

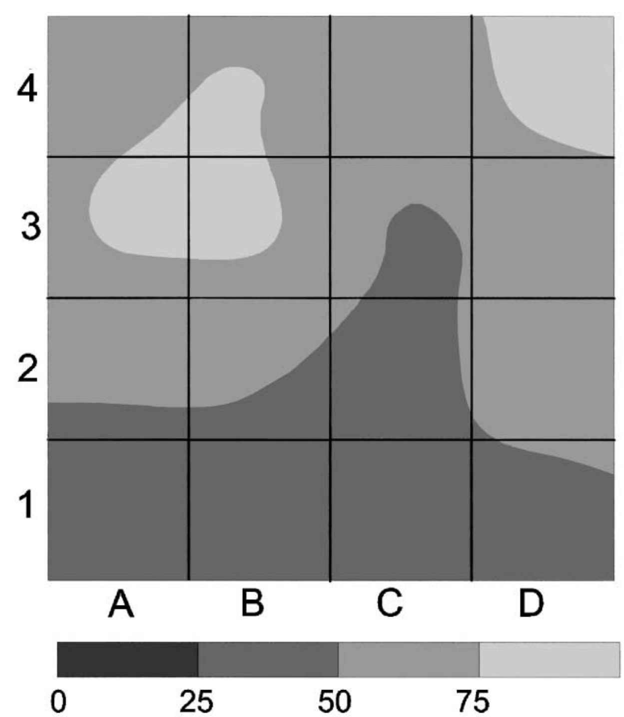

Fig. 2. Isopleth map of lichen biodiversity values.

Table 2
Scale for the interpretation of LB values on *Tilia* and deciduous *Quercus* trees on the Tyrrhenian side of Italy (Loppi et al., 2000b) and predicted yearly values of 98th percentiles of SO_2 (μg/m^3) for each naturality/alteration zone extrapolated from LB values, as deduced by Nimis et al. (1990)

LB values	% Deviation from normal conditions	Interpretation	Predicted SO_2 (98th percentile)
0–25	75–100	Alteration	> 50
25–50	50–75	Semi-alteration	15–50
50–75	25–50	Semi-naturality	5–15
> 75	0–25	Naturality	< 15

Table 3
Lichen species found in the three naturality/alteration zones[a]

	Semi-alteration			Semi-naturality			Naturality		
	% OGUs ($n=7$)	% Trees ($n=52$)	Mean *F*	% OGUs ($n=6$)	% Trees ($n=40$)	Mean F	% OGUs ($n=3$)	% Trees ($n=22$)	Mean *F*
Physconia perisidiosa	28.6	15.5	6.9	0.0	0.0	0.0	0.0	0.0	0.0
Caloplaca cerina	28.6	3.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Parmelia exasperata	28.6	3.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Anaptychia ciliaris	14.3	1.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Caloplaca ferruginea	14.3	1.7	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Diploicia canescens	14.3	1.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Normandina pulchella	14.3	1.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Lecanora allophana	14.3	1.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Physcia stellaris	14.3	1.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Phlyctis argena	14.3	1.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Lecanora carpinea	28.6	5.2	3.0	33.3	7.5	1.3	0.0	0.0	0.0
Leprocaulon microscopicum	14.3	1.7	8.0	16.7	2.5	1.0	0.0	0.0	0.0
Pertusaria albescens	28.6	3.4	1.0	0.0	0.0	0.0	33.3	4.5	4.0
Physcia aipolia	14.3	1.7	2.0	0.0	0.0	0.0	33.3	4.5	1.0
Hyperphyscia adglutinata	100.0	51.7	7.8	100.0	87.5	9.2	100	95.5	9.0
Physcia adscendens	100.0	77.6	7.5	100.0	80.0	9.3	100	100.0	10.0
Lepraria sp.	100.0	56.9	6.9	66.7	47.5	7.3	100	77.3	6.4
Parmelia subrudecta	100.0	56.9	4.5	100.0	67.5	4.5	100	90.9	6.8
Xanthoria parietina	100.0	34.5	2.0	100.0	55.0	4.5	100	45.5	3.6
Physconia grisea	85.7	43.1	6.9	100.0	77.5	7.6	100	90.9	8.8
Lecidella elaeochroma	85.7	53.4	5.8	100.0	65.0	5.9	100	27.3	4.8
Candelariella xanthostigma	85.7	46.6	4.3	100.0	42.5	4.1	100	77.3	6.4
Lecanora chlarotera	85.7	32.8	3.8	83.3	27.5	2.9	66.6	18.2	2.8
Phaeophyscia orbicularis	71.4	19.0	7.0	83.3	35.0	4.5	33.3	4.5	4.0
Parmelia subaurifera	71.4	24.1	4.3	83.3	37.5	4.2	100	90.9	7.7
Phaeophyscia chloantha	71.4	13.8	3.8	83.3	35.0	6.4	33.3	4.5	1.0
Candelaria concolor	71.4	25.9	4.3	100.0	70.0	7.8	100	54.5	4.8
Parmelia tiliacea	71.4	25.9	3.6	100.0	60.0	4.8	100	77.3	4.3
Phaeophyscia hirsuta	71.4	8.6	5.0	50.0	12.5	4.2	66.6	22.7	2.8
Physcia biziana	71.4	12.1	2.6	83.3	30.0	1.8	100	18.2	4.0
Parmelia sulcata	57.1	19.0	2.0	100.0	42.5	2.9	100	86.4	6.4
Parmotrema chinense	28.6	3.4	2.0	83.3	25.0	1.9	100	45.5	1.8
Evernia prunastri	42.9	5.2	1.3	66.7	20.0	3.0	100	68.2	3.3
Parmelia caperata	28.6	10.3	3.0	50.0	35.0	5.1	100	95.5	5.9
Amandinea punctata	57.1	13.5	2.7	50.0	10.0	6.5	100	59.1	6.9
Parmelia exasperatula	14.3	1.7	1.0	16.7	2.5	1.0	66.6	18.2	2.5
Physconia distorta	14.3	1.7	10.0	0.0	0.0	0.0	66.6	9.1	2.0
Arthonia radiata	28.6	5.2	2.0	16.7	2.5	1.0	33.3	4.5	2.0
Lecanora horiza	57.1	17.2	4.7	33.3	7.5	3.0	33.3	4.5	1.0
Mycomicrothelia confusa	14.3	3.4	10.0	33.3	10.0	8.0	33.3	4.5	10.0
Ramalina farinacea	0.0	0.0	0.0	33.3	5.0	1.0	0.0	0.0	0.0
Caloplaca cerinella	0.0	0.0	0.0	16.7	10.0	6.5	0.0	0.0	0.0
Parmelia quercina	0.0	0.0	0.0	16.7	2.5	5.0	0.0	0.0	0.0
Arthonia patellulata	0.0	0.0	0.0	16.7	2.5	3.0	0.0	0.0	0.0
Parmelia elengatula	0.0	0.0	0.0	16.7	2.5	3.0	0.0	0.0	0.0
Candelariella vitellina	0.0	0.0	0.0	16.7	2.5	2.0	0.0	0.0	0.0
Physconia servitii	0.0	0.0	0.0	16.7	2.5	2.0	0.0	0.0	0.0
Anisomeridium sp.	0.0	0.0	0.0	16.7	2.5	1.0	0.0	0.0	0.0
Arthrosporum populorum	0.0	0.0	0.0	16.7	2.5	1.0	0.0	0.0	0.0
Opegrapha atra	0.0	0.0	0.0	16.7	2.5	1.0	0.0	0.0	0.0
Candelariella reflexa	0.0	0.0	0.0	16.7	2.5	2.0	66.6	18.2	4.0
Ramalina fastigiata	0.0	0.0	0.0	16.7	2.5	1.0	33.3	9.1	1.0
Rinodina sophodes	0.0	0.0	0.0	16.7	10.0	5.3	33.3	9.1	1.5
Hypogymnia tubulosa	0.0	0.0	0.0	33.3	5.0	1.0	33.3	13.6	1.7
Parmelia acetabulum	0.0	0.0	0.0	0.0	0.0	0.0	100	18.2	1.3
Hypogymnia physodes	0.0	0.0	0.0	0.0	0.0	0.0	33.3	9.1	8.0
Usnea sp.	0.0	0.0	0.0	0.0	0.0	0.0	33.3	4.5	1.0

[a] % OGUs = percent of OGUs where the species was found; % Trees = percent of trees on which the species was found; F = mean frequency of the species on trees hosting it.

Table 4
Total species richness, mean species richness and β diversity (ratio of total species richness to mean species richness) in the three naturality/alteration zones

	Semi-alteration	Semi-naturality	Naturality
Total species richness	40	41	35
Mean species richness	8.5	11.2	13.8
β diversity	4.7	3.7	2.5

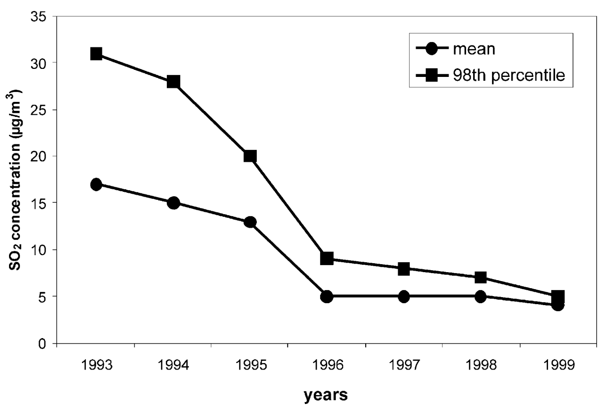

Fig. 3. Mean annual concentrations and yearly values of the 98th percentiles of SO_2 in Siena from 1993 to 1999 (ARPAT, unpublished data).

Areas classified as "altered" were lacking and most of the study area was "semi-altered" (36.2%) or "semi-natural" (51.4%); 12.4% of the area was "natural". The lowest LB values were found in the southern part of the study area while the highest LB values were found in the greenest part of the town, encompassing the football stadium and the main park, and at the northeastern edge of the urban area, which is located on a more elevated hill. By definition, towns are not natural environments and the fact that parts classified as "natural" were found could be due to localised humidity favouring lichen vegetation in the green area and exposure to prevailing winds promoting lower residence time of air pollutants on the hill. In general, at higher LB values, lichen frequencies did not seem to be affected by air pollution and variations in the epiphytic lichen communities presumably depended on other environmental factors.

The lichen vegetation in the "semi-altered" area (Table 3) is dominated by opportunistic species such as *Hyperphyscia adglutinata* and *Physcia adscendens*, which are *Xanthorion* elements very common throughout Italy, also occurring in rather polluted areas (Nimis, 2000). Besides the above species, the "semi-natural" area is characterized by *Candelaria concolor* and *Physconia grisea*; the "natural" area is characterized by the high frequency of *Parmelia* species (*P. subaurifera*, *P. sulcata*, *P. caperata*, *P. subrudecta*). This transition from *Xanthorion*-dominated to *Parmelion*-dominated lichen vegetation is generally interpreted as a gradient of decreasing anthropization and decreasing air pollution (Badin and Nimis, 1996). This general trend was confirmed by the increase in the percentage occurrence and frequency of several *Parmelia* species (*P. caperata, P. subaurifera, P. sulcata, P. tiliacea, P. subrudecta*) from the "semi-altered" to the "natural" zone (Table 3).

Although total species richness decreased from the "semi-altered" to the "natural" zone (Table 4), there was an opposite trend of increasing mean species richness; similarly, β diversity (ratio of total number of species to mean species richness), a measure of sample heterogeneity reflecting community differentiation (Whittaker, 1972), decreased from the "semi-altered" to the "natural" zone. This suggests that under conditions of human disturbance, opportunistic *Xanthorion* species, that are more competitive, tend to invade *Parmelion* synusiae, raising total species diversity.

Compared with the investigation of 1995 (Monaci et al., 1997; Monaci, in verbis), in the present survey more species were found (57 vs. 45) and higher mean and maximum LB values were scored (56.5 vs. 32 and 111 vs. 67, respectively). These features are probably determined by an improvement in air quality over time. The few analytical measurements of SO_2 available for the study area from 1993 to 1999 (ARPAT, unpublished data) show that levels are quite low and display a decreasing trend (Fig. 3). The yearly values of the 98th percentiles of SO_2 measured in the study area are in good agreement with the predicted SO_2 values extrapolated from the LB values, as deduced by Nimis et al. (1990) for La Spezia, which is 150 km NW of Siena (Table 2). Furthermore, the mean LB value of the 1995 survey (32 ± 13.8, Monaci, in verbis) indicates yearly values of the 98th percentiles of SO_2 in the range 15–50 $\mu g/m^3$, which are in perfect agreement with the 20–31 $\mu g/m^3$ SO_2 measured analytically between 1993 and 1995.

Concentrations of SO_2 measured in Siena from 1996 to 1999 (4–5 $\mu g/m^3$) are probably too low to kill or damage lichens. However, in urban environments, in addition to SO_2, the simultaneous occurrence of the phytotoxic gaseous pollutants NO_X is typical, and combined effects can therefore be expected. Synergistic effects are observed when concentrations are below or at the threshold for individual injury response, while at relatively high doses antagonistic effects occur (Balaguer et al., 1997). Mean annual levels of NO_X in Siena in the period 1993–1999, being in the range 30–47 $\mu g/m^3$, were stable and quite low, especially if compared with the 100–150 $\mu g/m^3$ recorded in other urban areas of Tuscany (Loppi and Corsini, 1995; Loppi et al., 1996a, 1996b, 1996c). Synergistic effects could therefore explain the absence or scarcity of certain sensitive lichen species, especially *Parmelia* ones, from the "semi-altered" zone, despite the low levels of SO_2 and NO_X.

Although it is well-documented that epiphytic lichens respond to atmospheric pollution, a negative relationship of most species was observed only for SO_2, or the combination of SO_2 and NO_X which generally are strongly correlated, and thus biodiversity counts can only be used as a monitor for SO_2 (Van Dobben and Ter Braak, 1999). However, in field monitoring it is very difficult to separate the effects of many intercorrelated variables and this is especially true for pollution studies, as pollutant concentrations tend to be correlated with the general level of human activity and are therefore correlated among each other (Van Dobben and Ter Braak, 1998). Furthermore, urban environments are highly complex and air pollutants and lichen species are both influenced by local topography and climate.

Acknowledgements

The stay in Siena of D. Ivanov was supported by a NATO-CNR grant.

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