Acta Bot. Neerl. 45(4), December 1996, p. 563–570

Lichens as long-term biomonitors of air quality in central Italy

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SUMMARY

The results of a long-term study (data of 1978 and 1993) performed in central Italy using epiphytic lichens both as indicators and monitors (accumulators) are presented. Floristic data showed that air quality in the study area did not change markedly in this 15-year period and is currently fairly good. Similarly, the concentrations of trace elements in *Parmelia caperata* thalli showed no substantial change, with values similar to those in lichens of unpolluted areas. The concentration of ^{137}Cs in *P. caperata* and *Lobaria pulmonaria* thalli doubled after the Chernobyl accident, but was low compared to other European areas.

Key-words: air quality, biomonitors, Italy, lichens.

INTRODUCTION

Changes in lichen flora due to air pollution are well documented (Hawksworth *et al.* 1973; Gilbert 1992). According to James & Wolseley (1992), continuous monitoring of lichen growth and succession, with concomitant monitoring of other environmental parameters, provides useful information on the health of ecosystems. Such studies have been few, but their results are important since they give a picture of modifications to lichen communities as a result of environmental changes.

The best method of investigating air quality with lichens is to study the lichen flora of an area prior to the onset of pollution and again afterwards, to detect any changes in species composition (Wetmore 1988). This, however, is seldom possible due to a lack of baseline information on lichens. In The Netherlands, Van Dobben (1983, 1993, 1996) and Van Dobben & De Bakker (1990, 1996) compared the lichen flora of the same area in time and found that certain species disappeared due to SO_2 pollution and others expanded their distribution in relation to decreasing SO_2 and increasing ammonia concentrations. In England, impoverishment of the lichen flora caused by heavy air pollution with SO_2 has been described in many areas (Hawksworth *et al.* 1973). However, after 20 years of improving conditions, Bates *et al.* (1991) found little evidence of lichen recolonization. In the USA, Wetmore (1981, 1989) documented floristic changes in some areas but not in others.

In addition to floristic changes, variations in lichen trace element content in time can provide useful evidence for trends in ambient pollution burdens. Lawrey & Hale (1988) compared S and Pb concentrations in lichen thalli at various points in time and found increasing levels of sulphur and decreasing levels of lead. Lawrey (1993) followed the concentrations of sulphur, nitrogen and some heavy metals in lichens of areas subject to heavy air pollution and reported a declining trend for all the elements considered. In Finland, Halonen *et al.* (1993) found increases and reductions in the concentrations of certain elements accumulating in lichens monitored periodically at permanent sites.

Variations in radionuclide content of lichens collected before and after the Chernobyl accident have enabled evaluation of the occurrence of ^{137}Cs arising from the Ukraine nuclear reactor (Hofmann *et al.* 1993).

The aim of the present study was to use epiphytic lichens as long-term indicators and monitors (accumulators) of air quality in central Italy. The opportunity was provided by a lichen collection from 1978 in the herbarium of the University of Siena.

MATERIALS AND METHODS

The study was performed in a remote area of Tuscany (central Italy), near the village of Montieri, 35 km SW of Siena and 40 km N of Grosseto. The area is mountainous, with an elevation of 700–750 m. The climate is Mediterranean, very humid, with a mean annual temperature of 12°C and a mean annual rainfall of 1100 mm; in winter long frosts and snowfall are common (Barazzuoli *et al.* 1993). The vegetation consists of chestnut (*Castanea sativa*) groves and coppices. The village of Montieri has 1400 inhabitants; domestic heating, mostly wood and secondarily kerosene and fuel oil stoves, is the main local source of atmospheric pollution.

In 1978, lichens were collected in a chestnut grove as a floristic contribution from this area. Due to lack of lichenological experience of the collector, the material was not worked up. The samples, kept in Siena, were still unidentified; the epiphytic ones were checked in the framework of this study. In November 1993, a new collection of epiphytic lichens was made in the same area. It should be noted that chestnut groves are assimilable to cultivations, and are maintained unchanged by men. This implies that, despite ageing, ecological conditions have probably remained constant. The floristic lists of the two collections were compared for differences attributable to changes in atmospheric pollution. The latter was determined indirectly by analysing the trace element content in thalli of the lichen *Parmelia caperata*, a species widespread in the study area and commonly used in bioaccumulation studies in Italy (Bargagli *et al.* 1987a; Nimis *et al.* 1993; Loppi *et al.* 1994; Loppi & Bargagli 1995). Due to the scarcity of 1978 material, no replication was possible.

Lichen samples were air-dried and sorted to remove as much extraneous material as possible. Since certain metals accumulate in foliose lichens in zones according to age, i.e. exposure time (Hale & Lawrey 1985; Bargagli *et al.* 1987b), only the outermost 3 mm of the thalli were detached and analysed. This part is physiologically the most active and has an age of about 1 year (Fisher & Proctor 1978). In *P. caperata* it is distinguishable by colour, lacks rhizinae and is easily separated from the bark. The samples were then powdered and homogenized and about 150 mg were mineralized in a pressurized digestion system (Teflon bomb) with concentrated HNO_3 for 8 hours at 120°C. Trace elements were determined by: (i) atomic absorption spectrophotometry, using a graphite furnace for Cd, Co, Mo and Pb, a hydride generator for As and Sb, and the cold vapour technique for Hg; (ii) inductively coupled plasma emission spectrometry for Al, B, Ba, Cr, Cu, Fe, Mn, S, Sr, Ti, V and Zn. Trace element concentrations were expressed on a dry weight basis. Analytical quality was checked by analysing the reference material SRM N. 1547 'peach leaves'.

Comparison of the content of ^{137}Cs in the 1978 and 1993 samples also gave an indication of the amount of ^{137}Cs arising from the Chernobyl accident in 1987. ^{137}Cs analyses were performed on whole thalli of *Parmelia caperata* and *Lobaria pulmonaria.* Samples were sorted to remove as much extraneous material as possible, oven-dried at 110°C for 12 hours and ashed at 400°C for 12 hours in order to concentrate the cesium (Strandberg 1994). ^{137}Cs activity was measured for 24 hours by gamma spectrometry using a Ge-detector with an efficiency that ranged from 21% to 32%. Results were decay-corrected to the date of sampling and expressed in $Bq{\cdot}g^{-1}$ dry weight.

RESULTS AND DISCUSSION

Table 1 gives the complete floristic list of lichens found during the two collections, along with their abundance. A total of 76 taxa was found. Species common to both collections (33) maintained roughly the same abundance and were the principal ones used for the ecological characterization of the environment (i.e. *Lobaria pulmonaria* and several *Parmelia, Pertusaria, Lecanora* and *Cladonia* species). In general, the floristic composition of the chestnut wood surveyed consisted of *Lobarion* species. This vegetation is characterized by foliose species belonging to the genera *Lobaria, Nephroma, Peltigera, Parmelia* and several crustose species; the most common and constant element of the community is *Lobaria pulmonaria,* a species which is also regarded as an indicator of old forests with a long ecological continuity (Barkman 1958). The European distribution of this vegetation extends from SW Norway to the Mediterranean mountains, with an oceanic–montane distribution (Rose 1988). In southern Europe, *Lobarion* communities develop in old *Quercus*-dominated woods in hills up to 500 m, and in *Castanea* woods above this elevation, up to 1000 m (Rose 1988).

Lobarion communities declines drastically in Europe due to air pollution and forest management (Rose 1988). Toxic air pollutants such as SO_2, NO_x and acid rain have had a doubly detrimental effect, both by direct phytotoxicity and by secondary bark acidification (Gilbert 1986; Gauslaa 1995). This has caused the disappearance or the substitution of *Lobarion* vegetation with other, more acidophilous, lichen communities, such as the *Pseudevernietum furfuraceae* or the *Parmeliopsidetum ambiguae* (James & Wolseley 1992). An example of the consequences of drastic changes in forest management occurred in France, where the practice of cultivating forests of autochthonous species in small areas, thus eliminating large clearings that favour *Lobarion* development, and the selective cutting of trees 30–40 cm in diameter, led to the near extinction of *Lobarion* vegetation (Rose 1988).

The 1978 collection contained 48 epiphytic taxa, whereas 62 entities were collected in 1993 (Table 1). Fifteen species present in 1978 were not found in 1993. Some of these species, such as *Arthopyrenia punctiformis, Candelariella reflexa, Mycomicrothelia confusa, Rinodina pyrina* and *Rinodina sophodes,* may have been overlooked in 1993. The same reasoning holds for the 29 species found only in 1993 and not in 1978. For other larger species, such as *Degelia plumbea,* a fruitless search was made, and thus it could by hypothesized that disappearance has occurred. However, some macrolichens, such as *Lobaria amplissima,* may have reappeared in time.

Data on species sensitivity to air pollution (Hawksworth & Rose 1970; Deruelle 1977) suggest that air quality in the study area has not changed markedly in the last 15 years and is currently fairly good. The floristic survey also suggests that the management of the chestnut wood has remained practically unchanged. The only indication of possible

Table 1. Floristic list of epiphytic lichens collected in 1978 and 1993 (1=found only once, 2=rare, 3=not frequent, 4=frequent). Nomenclature follows Nimis (1993)

Species	1978	1993
Chrysothrix candelaris	4	4
Cladonia pyxidata	4	4
Evernia prunastri	4	4
Lecanora chlarotera	4	4
Lecanora leptyrodes	4	4
Lecidella elaeochroma	4	4
Lobaria pulmonaria	4	4
Parmelia caperata	4	4
Lecanora carpinea	4	4
Parmelia saxatilis	4	4
Parmelia sulcata	4	4
Parmelia tiliacea	4	4
Pertusaria albescens	4	4
Pertusaria albescens v. *corallina*	4	4
Pertusaria pertusa	4	4
Phlyctis argena	4	4
Ramalina farinacea	4	4
Ramalina fastigiata	4	4
Cladonia coniocraea	4	3
Pertusaria hemisphaerica	4	3
Pertusaria leucostoma	4	3
Physconia distorta	4	3
Cladonia macilenta	3	4
Parmelia glabratula ssp. *glabratula*	3	4
Calicium salicinum	3	3
Lecanora argentata	3	3
Parmelia subaurifera	3	3
Peltigera horizontalis	3	3
Peltigera praetextata	3	3

recent change to the wood caused by man is the disappearance of *Degelia plumbea*, a typical *Lobarion* species very sensitive to microclimatic changes (Nimis 1993).

The substantially unchanged situation of air pollution in the last 15 years was also confirmed by the concentrations of trace elements in *Parmelia caperata* thalli (Table 2). No substantial change is apparent for heavy metals such as As, Cd, Hg, Pb, as well as sulphur, which can be taken as an indirect estimate of SO_2 pollution. The concentrations of lithogene elements (Al, Fe, Mn, Ti) were also more or less constant, indicating similar possible contamination of samples by wind-blown soil particles (Bargagli 1995; Bargagli *et al.* 1995; Loppi *et al.* 1996). In general, the present values are similar to those reported in *P. caperata* from unpolluted areas of Italy (Bargagli *et al.* 1987b, Nimis *et al.* 1993; Loppi *et al.* 1994; Loppi & Bargagli 1995) and this further confirms that the study area is a remote one which has not been subject to significant air pollution, at least in the last 15 years.

Table 3 reports the concentrations of ^{137}Cs in *P. caperata* and *L. pulmonaria* thalli. Both species showed their highest values in 1993 samples, with a similar 1993/1978 ratio (1·69 and 1·70, respectively), indicating that the study area is affected by post-Chernobyl ^{137}Cs contamination. The values measured at Montieri are lower than those generally

Table 1. *Continued.*

Species	1978	1993
Physconia venusta	3	3
Physcia stellaris	3	2
Physconia servitii	3	2
Pertusaria amara f. pulvinata	1	3
Parmelia acetabulum	4	—
Pertusaria hymenea	4	—
Anaptychia ciliaris	3	—
Candelariella reflexa	3	—
Cladonia polydactyla	3	—
Degelia plumbea	3	—
Rinodina pyrina	3	—
Calicium viride	—	4
Cladonia parasitica	—	4
Lecidella euphorea	—	4
Lepraria lobificans	—	4
Parmelia elegantula	—	4
Parmelia quercina	—	4
Pertusaria amara	—	4
Haematomma ochroleucum v. *porphyrium*	—	3
Lecanora allophana	—	3
Lecanora horiza	—	3
Lobaria amplissima	—	3
Ramalina fraxinea	—	3

Other species: Amandinea punctata (1993, 1), *Arthonia patellulata* (1993, 1), *Arthonia radiata* (1993, 1), *Arthopyrenia punctiformis* (1978, 1), *Bryoria* sp. (1978, 1), *Caloplaca holocarpa* (1993, 1), *Cladonia caespiticia* (1993, 1), *Cladonia furcata* (1993, 1), *Dimerella pineti* (1993, 1), *Hyperphyscia adglutinata* (1978, 1), *Lecania cyrtella* (1993, 1), *Lecanora expallens* (1993, 2), *Lecanora meridionalis* (1978, 1), *Mycomicrothelia confusa* (1978, 2), *Normandina pulchella* (1993, 1), *Parmelia exasperatula* (1993, 2), *Peltigera lactucifolia* (1978, 2), *Pertusaria flavida* (1993, 2), *Phlyctis agelaea* (1993, 2), *Physcia semipinnata* (1978, 2), *Rinodina exigua* (1993, 1), *Rinodina sophodes* (1978, 1), *Scoliciosporum chlorococcum* (1993, 1), *Tephromela atra* v. *torulosa* (1993, 1), *Xanthoria parietina* (1993, 1).

reported in lichens from other parts of Europe (Seaward *et al.* 1988; Bartók & Mócsy 1990; Sawidis & Heinrich 1992). As far as Italy is concerned, Adamo *et al.* (1989) reported values in the range 1·3–2·5 Bq·g^{-1} in thalli of *Stereocaulon vesuvianum* collected on Mt Vesuvio at elevations ranging from 370 to 960 m. Hofmann *et al.* (1993) found no ^{137}Cs increase in thalli of *Usnea articulata* from Sardinia, with values of less than 0·1 Bq·g^{-1}. For Tuscany, Feige *et al.* (1990) reported radiocaesium (^{134}Cs + ^{137}Cs) concentrations of 0·2 Bq·g^{-1} in *Cladonia* thalli collected in coastal area at Castiglione della Pescaia (45 km SSW of Montieri) and values ranging from 2 (*Ramalina fastigiata*) to 11 (*Lasallia pustulata*) Bq·g^{-1} in lichens collected on Mt Amiata (60 km SE of Montieri) at an elevation of about 1200 m. However, if the values reported by Feige *et al.* (1990) for *L. pulmonaria* collected on Mt Amiata (4·3 Bq·g^{-1}) are corrected for the ^{134}Cs/^{137}Cs ratio and recalculated for 1993, a value of about 1·2 Bq·g^{-1} emerges. This value is similar to that measured in samples of *L. pulmonaria* collected at Montieri in 1993 (0·97 Bq·g^{-1}). In general, the values measured at Montieri in thalli of 1993 are intermediate between those of Castiglione della Pescaia and Mt Amiata and this agrees well with the elevations of these localities and thus probably with the amount of rain falling immediately after the Chernobyl accident. In fact, Nimis *et al.* (1986) showed that

Table 2. Trace element concentrations (μg·g^{-1} dw) in *Parmelia caperata* thalli collected in 1978 and 1993. Background = range of values found in unpolluted areas in Italy (Bargagli *et al.* 1987b; Loppi *et al.* 1994; Loppi & Bargagli 1995; Nimis *et al.* 1993)

	1978	1993	Background
Al	1777	2024	150–2200
As	2·96	2·67	0·20–3·55
B	15·94	9·11	5·1–25·4
Ba	24·52	24·83	7·9–59·7
Cd	0·472	0·404	0·05–0·70
Co	0·363	0·305	0·22–1·02
Cr	3·59	1·53	1·25–6·26
Cu	3·64	5·59	3·75–12·3
Fe	746	805	492–1037
Hg	0·468	0·272	0·05–0·55
Mn	78·8	77·8	10·9–87·4
Mo	0·419	0·289	0·21–0·89
Pb	31·14	32·68	2·1–52·6
S	689	824	596–1312
Sb	0·288	0·368	0·05–0·70
Sr	53·9	44·4	12·3–57·4
Ti	50·0	47·7	29·7–117·8
V	1·28	1·31	0·74–5·76
Zn	36·1	49·0	22·2–55·4

Table 3. Concentrations of ^{137}Cs (Bq·g^{-1}) in *Parmelia caperata* and *Lobaria pulmonaria* thalli collected in 1978 and 1993

Species	1978	1993
Parmelia caperata	0·29	0·49
Lobaria pulmonaria	0·57	0·97

radiocaesium was deposited proportional to the rainfall of the first 10 days after Chernobyl. This fact is indirectly strengthened by the substantial difference between the amount of ^{137}Cs in *P. caperata* and *L. pulmonaria*: values of the latter in 1978 were similar to those of the former in 1993 and this suggests that the absorption of ^{137}Cs is not simply a passive phenomenon since both species are of similar morphology. Differences in these concentrations can be explained on the basis of the different ecological requirements of the species, *L. pulmonaria* being much more aerohygrophytic than *P. caperata*. The former may thus have absorbed much more water and/or air moisture and consequently much more ^{137}Cs.

CONCLUDING REMARKS

The results of the present survey indicate that air quality in the study area has remained relatively unchanged in the 15-year period of the study. However, Montieri is located in an area without any substantial local source of air pollution and is not a recipient of contaminants arriving by long-range atmospheric transport. The only negative point regarded ^{137}Cs, which doubled after the Chernobyl accident to levels that are nevertheless low.

The present results also confirm the importance of long-term lichen biomonitoring to assess environmental changes in time, and the utility of coupling floristic data with elemental analysis of vegetation.

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