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LICHENS AS BIOMONITORS OF SULPHUR DIOXIDE POLLUTION IN LA SPEZIA (NORTHERN ITALY)

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Abstract: Lichens epiphytic on olive trees were used as biomonitors of sulphur dioxide pollution in La Spezia (Northern Italy). The method adopted was designed to avoid subjectivity at all stages, from the sampling strategy to data analysis. Thus, lichen data are expressed by an index that does not depend on any sensitivity scale; data analysis relies on multivariate methods of classification and ordination, and the pollution maps have been produced by automatic mapping programmes. The index, based on the frequency of species within a sampling grid, showed a very high statistical correlation with pollution data measured by recording gauges. The results of classification and ordination indicate that *Parmelia caperata* is the species with a distribution best related to the lichen index. The quality of air pollution data obtained from biomonitors is discussed.

Introduction

The sensitivity of lichens to air pollution, and particularly to sulphur dioxide, is well-known. According to James (1973), over two hundred papers on lichens and air pollution had been published by 1973, a number that has increased still more in recent years. Sigal (1988) claims that lichens may be useful as bio-indicators, but not as biomonitors, i.e. they exhibit injury symptoms when exposed to phytotoxic pollutants, but do not allow prediction of exact pollutant concentrations. This statement probably refers to the rather subjective methods adopted by several lichenologists in air pollution studies. The main point of weakness of the numerous Indices of Air Pollution (IAP) used to predict pollution levels from lichen data is that most of them rely on more or less subjectively established ' sensitivity scales '. Even accepting a given scale as valid, its extrapolation to areas with a different climate and/or with a different lichen flora is not justified (Nimis 1986). Ammann *et al.* (1987) and Liebendoerfer *et al.* (1988), have recently discussed an IAP which does not depend on any sensitivity scale; the index is based on the sum of the frequencies of lichen species within a sampling grid. It showed a highly significant correlation with the combined concentrations of several pollutants measured by recording gauges in the town of Biel (Switzerland).

This study is an attempt to test whether the approach proposed by Ammann *et al.* (1987) could be used for monitoring SO_2 pollution in Italy under different climatic conditions. In planning the study, we tried to reduce subjectivity at all stages, including the sampling strategy, the selection of indicator species, and the drawing of maps. For this reason, we do not use any pre-established sensitivity scale to compute IAPs. Lichen data are compared with actual

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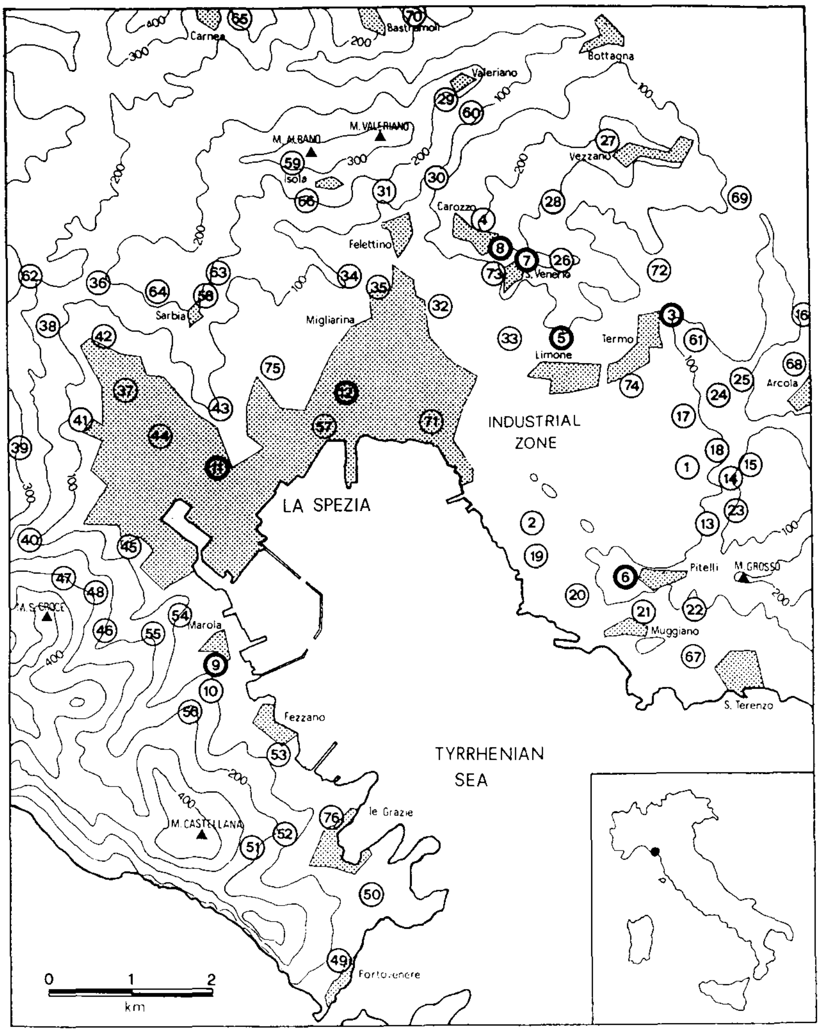

FIG. 1. Map of the survey area with the location of the 76 sampling stations. The numbers in bold circles refer to the eight stations near the automatic gauges recording SO_2 pollution.

pollution values, data elaboration strongly relies on methods of multivariate analysis, and all maps have been obtained by automatic mapping programmes.

Survey area, Data and Methods

The survey area (*c.* 80 km²) includes the town of La Spezia (Liguria, Northern Italy, 110 000 inhabitants) and its surroundings. It is bordered to the south by the sea and elsewhere by low hills with cultivations of *Olea sativa*. An industrial zone and a large coal power-station are located east of the town (Fig. 1). The climate is transitional between suboceanic and Mediterranean climate-types, with a short dry period during the summer (Fig. 2). In the area there are eight continuous

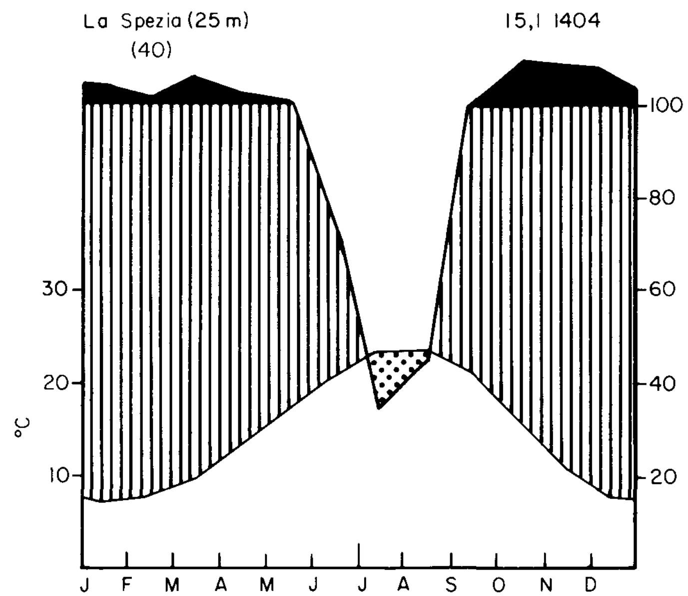

FIG. 2. Climatic diagram of La Spezia (Walter & Lieth, 1960). The x-axis = the months of the year, from January to December. The y-axes = mean monthly temperatures (lower line) and mean monthly precipitations (upper line). The dotted area indicates the water deficit period.

coulometric titration monitors (Philips, PW 9700) of the National Agency for Electric Energy (ENEL), recording SO_2 concentrations since 1978. The mean yearly values of the 50° percentile in the period 1978–1987 ranged from 12·4 μg m^{-3} (station 3, Fig. 1), to 21·8 μg m^{-3} (station 9), whereas those of the 98° percentile ranged from 58·0 μg m^{-3} (station 6) to 109·1 μg m^{-3} (station 11).

All releves of lichen vegetation were on *Olea sativa*. A total of 365 releves were carried out at 76 stations, the location of which are shown in Fig. 1. The sampling strategy was as follows:

a) a sampling station was placed at all sites with at least eight trees satisfying the standards adopted by Liebendoerfer *et al.* (1988). Eight stations were located near the recording gauges;

b) in each station releves were carried out on at least four randomly selected trees;

c) releves were taken using a sampling grid of 30 × 50 cm, subdivided into ten rectangles, placed on the boles at a height of 1·3 m (the centre of the grid was positioned in the part of the bole with highest lichen coverage);

d) a releve listed all species found within the grid, with the number of grid units in which every species occurred (frequency value) being computed;

e) the sum of the frequency values of all species (with the exception of three, see later) is the IAP of the releve; the IAP of the station is the average of the IAP values of all releves within the same station.

A matrix with the average frequency data of each species in each station (Table 1) was submitted to ordination with Principal Component Analysis (Wildi & Orloci 1983), using Cross Product as a resemblance measure after transformation of the data by deviation from expectation (Reciprocal Ordering, see Orloci 1978). The ordination allowed detection of a compositional gradient related to air pollution, and selection of indicator species.

The same matrix was submitted to a numerical classification of the species, using Euclidean Distance as a resemblance measure and Complete Linkage as a clustering algorithm (Wildi & Orloci 1984), to find groups of species with similar distribution. Distribution maps of all species were obtained by processing the average frequency data with the program SURFER (Golden Software Inc., Colorado). The results of numerical classification and the analysis of the maps

TABLE 1. *Frequency values of the species at the 76 stations*

	Species	Station number*																																	
		43	37	42	35	53	45	19	75	34	76	54	64	61	36	32	49	33	31	2	56	50	59	20	9	38	10	8	41	7	40	16	1	68	55
21	*Parmelia sulcata*								1‡									1	1											1		1			
19	*P. saxatilis*														1				1	1			2	1											1
3	*Cladonia* sp.			1			1		1						1			2	2	2		1	2	1				1	1	1					
9	*Hypogymnia physodes*																	1																	
5	*Evernia prunastri*								1																									1	
29	*Physcia clementei*			1																															
16	*Normandina pulchella*																									1									
12	*Lecanora symmicta*																																		
11	*Lecanora conizaeoides*																																		
8	*Hyperphyscia adglutinata*																																		
4	*Collema furfuraceum*																												1						
26	*Pertusaria hymenea*																																		
32	*Usnea* cf. *hirta*																																	1	
10	*Lecanora chlarotera*																																	1	
13	*Lecidella elaeochroma*																														1				
27	*Pertusaria pertusa*																						1												
25	*P. hemisphaerica*																																		
31	*Scoliciosporum chlorococcum*			1														2		1			1							1					
30	*Physcia tenella*																																		
2	*Candelariella xanthostigma*																														1				
1	*Buellia punctata*								1					1				1								1				1	1				
7	*Heterodermia obscurata*	1		3	2								1	2															2		1	1	1	1	
23	*Parmotrema chinense*			1									2		2														1		1			1	1
24	*Pertusaria amara*						2									2	1	3				1									1		1		1
28	*Physcia adscendens*	3	3	1		1		1	1	1	1	4	1	1				1							1	1		1		1	1				
22	*Parmelia tiliacea*								3	4	2	3	1				2	1	2	2				2			1	1	2	3	3	1			
20	*P. subrudecta*			1							1	1	1						1			1				2	4	4	2	3	5	2		1	
18	*P. glabratula*									1		1	2	1	1			1	1	1				2		5			1	2				1	
15	*Leprocaulon microscopicum*	2	5	2	5	2	3	5	1	2	1	1	1	2	1	1	4	2	3	2	4	3	3	5	4	4	2	2	4	3	5	2	2	2	2
6	*Haematomma ochroleucum*			1	1	5	4	5	1	3	5	3	1	1	2	2	4	2	2		2	2	2	3	1	1	1	2	2	2	3	1		2	3
14	*Lepraria incana*					3	2		1	1			2	3	5	3	4	2	5	5	3	3	3	5	5	2	3	1	1	1		2	2	2	3
17	*Parmelia caperata*		1	1					1		1		3	2	2	2	3	3	3	2	1	2				1	2	3	3	2	5	4	5	5	5

	Species	Station number*																																	
		73	5	63	18	15	23	4	72	3	66	30	25	17	62	48	69	46	67	47	39	14	21	6	22	70	24	65	13	58	26	28	27	60	29
21	*Parmelia sulcata*		1		1		2	2	1			1	1		1						2	4	1	2	1	1	1	3	2	1		1	2	3	3
19	*P. saxatilis*	2	1	2																1	4	3		1		1	1	3	3		1		1	1	3
3	*Cladonia* sp.	1	1	2	1	1					2		1	1				1				1	1			5	5	3	3	1	3	1	1	2	3
9	*Hypogymnia physodes*							1				1																				1	1		1
5	*Evernia prunastri*				1														1													1			1
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25	*P. hemisphaerica*																								1	2	1								
31	*Scoliciosporum chlorococcum*											1	1				1		1				2									1			
30	*Physcia tenella*																						3												
2	*Candelariella xanthostigma*											1					1		1				1									2	2	1	2
1	*Buellia punctata*																1		3				2	2	1	1									
7	*Heterodermia obscurata*									1							1	1		1															
23	*Parmotrema chinense*				1											1				1	2				3	1		2				1		2	1
24	*Pertusaria amara*	1	1						1					2				1				2		1		3	3	1					1	1	
28	*Physcia adscendens*				1			1				1	1	1	1	2	1	1		1	1	1	2	3	1								1		
22	*Parmelia tiliacea*	2	1	1	1		1	2			1				1	1	1		1	2	1	2	1	3	1	1			2	1	1	1	1		1
20	*P. subrudecta*	1		1				1							2	2	2	1		2	1							1		2		1		1	1
18	*P. glabratula*	3	2	1	1	1	1	1			2	1					1	1		3	3	1	5	5	3			2	5	4	5	3	2	3	3
15	*Leprocaulon microscopicum*	2	1	1	1	1		1	3	5	4	1	1	1	3	3	2	3	2	3	2	1		1				1		2	2	1	2	1	1
6	*Haematomma ochroleucum*	1	1	3	2	1	1	2	2	2	1	4	3	4	3	4	3	4	3	4	5	3	3	4	2	1	1		1	1	1	2	2	3	2
14	*Lepraria incana*	2	2	2	2	1	2	1		2	1	2	2	1	1		2	2		3	2	2							1	1		1	1	2	2
17	*Parmelia caperata*	4	4	5	5	5	5	5	5	4	5	5	3	5	4	5	5	4	5	5	4	4	2	1	2	5	4	5	5	5	5	5	5	5	5

*Stations are numbered as in Fig. 1.
‡Frequency is expressed on a 5-class ordinal scale, with intervals of 20%.

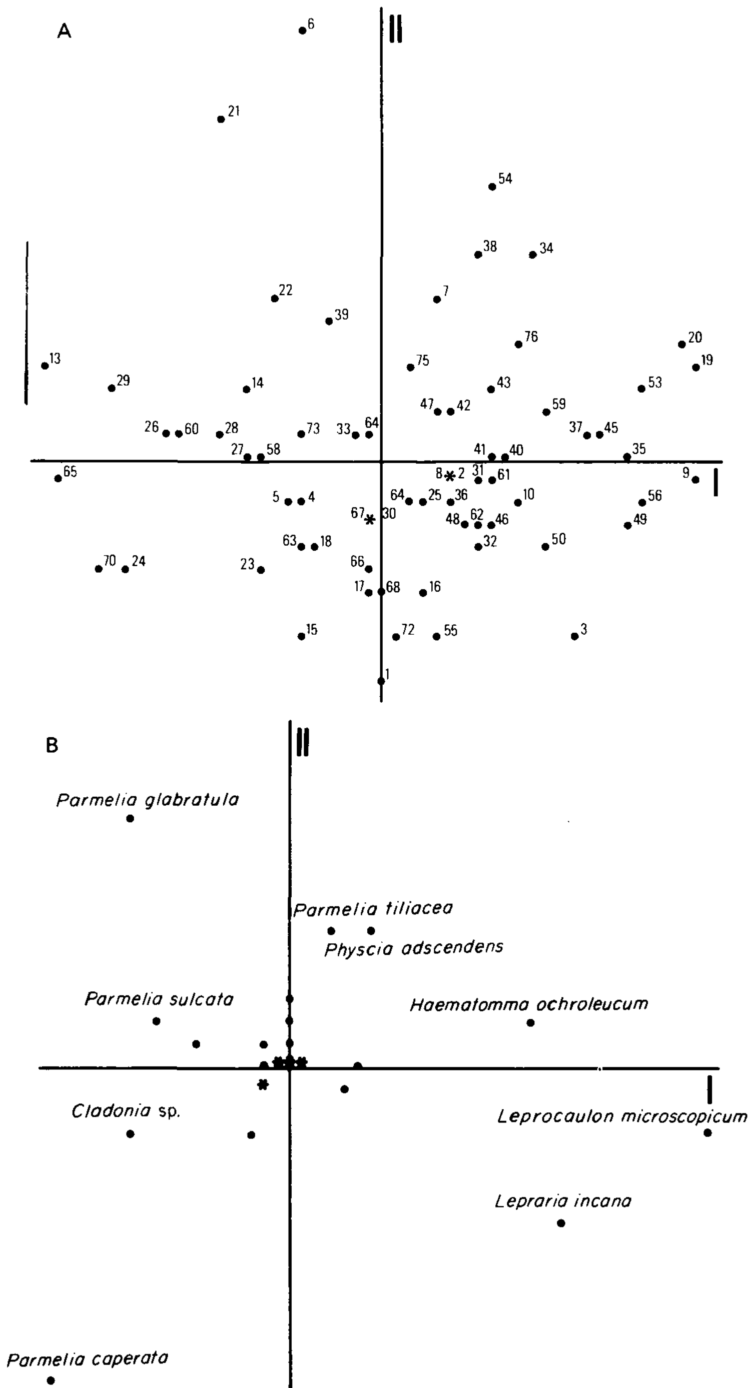

FIG. 3. Reciprocal Ordering according to the two first Principal Components (I and II) of (A) the 76 stations and (B) the 32 species based on the data of Table 1. In (A) the stations are numbered as in Fig. 1. In (B) only the species which have high scores on the first two Principal Components are indicated.

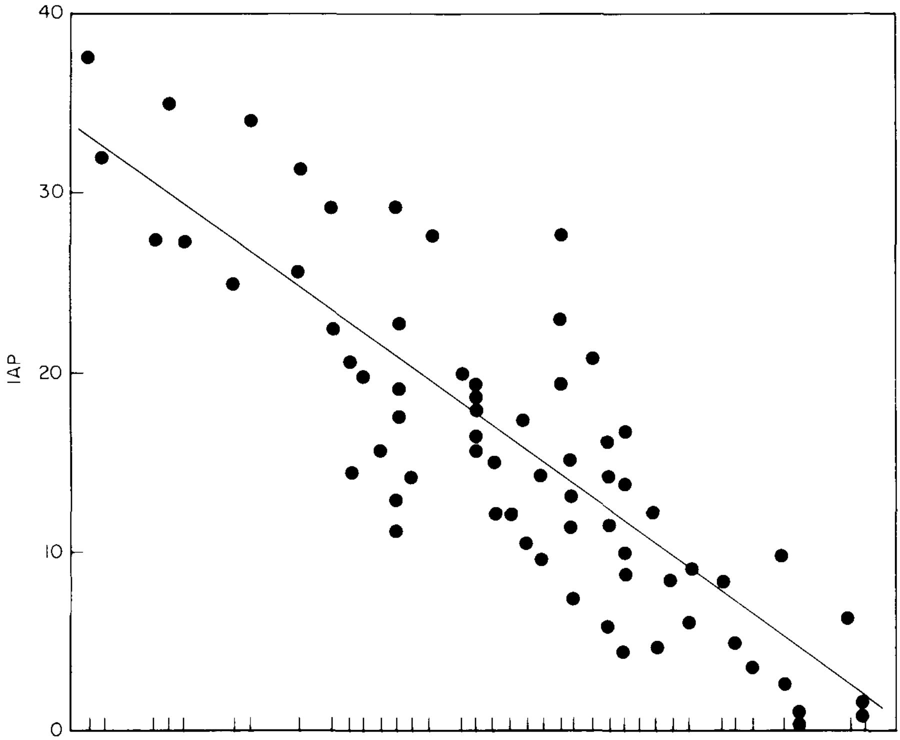

FIG. 4. Interpretation of the ordination of stations. The x-axis = the score of the first Principal Component axis (Fig. 3A), the y-axis = the IAP score of the stations.

allowed us to group the species according to their distribution in the survey area, and to exclude a group of three species with anomalous distribution from the computation of the IAP.

Statistically significant correlations were found between IAPs values of the eight stations near the recording gauges and the real pollution data. The IAP values of each station were used to construct a pollution map by the program SURFER. The program transforms the original discrete data structure into a continuous distributional model allowing prediction of pollution values for each point of the map.

Results

The matrix of 76 stations and 32 species is reported in Table 1. There was a remarkable prevalence of acidophytic, non-nitrophytic and relatively aerohygrophytic lichens. This probably reflects the acid pH of *Olea* bark, the scarce use of fertilizers, and the suboceanic climate of the area.

The results of Reciprocal Ordering, based on the matrix of Table 1 are shown in Fig. 3A (stations) and 3B (species). The first Principal Component (PC) accounts for 86·5% of the total variance; its ecological meaning has been interpreted on the basis of Fig. 4, where the x-axis orders the stations as on the first PC and y-axis reports the IAPs values of each station. The results show that the

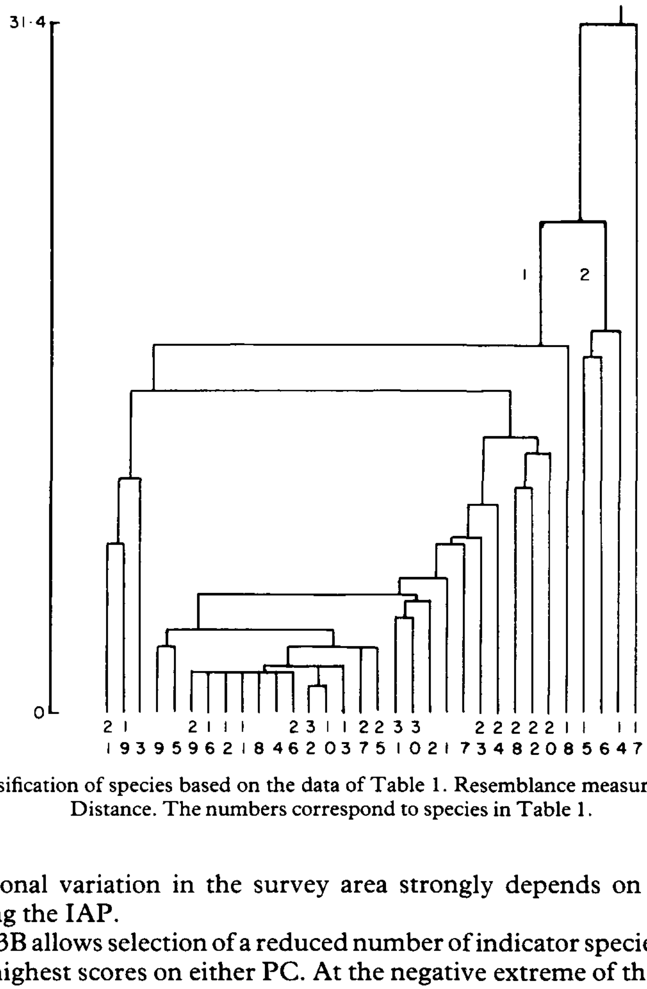

FIG. 5. Classification of species based on the data of Table 1. Resemblance measure is Euclidean Distance. The numbers correspond to species in Table 1.

compositional variation in the survey area strongly depends on the factors influencing the IAP.

Figure 3B allows selection of a reduced number of indicator species, i.e. those with the highest scores on either PC. At the negative extreme of the first PC is *Parmelia caperata* (indicating high IAP values); at the positive extreme are *Leprocaulon microscopicum, Lepraria incana* and *Haematomma ochroleucum* (indicating low IAP values).

In the dendrogram of Fig. 5, three main species clusters are formed. Cluster 3 consists of *P. caperata* only, cluster 2 includes *Leprocaulon, Haematomma* and *Lepraria,* and all other species join in cluster 1. To test the distribution of the indicator species in the survey area, distribution maps have been constructed for each species. The species of each cluster have different distribution patterns, as shown in Fig. 6(A–C), reporting the distribution maps of three species, one for each cluster. The frequency of *Parmelia caperata* (cluster 3, Fig. 6C) tends to decrease regularly from peripheral areas to the town centre, *Lepraria incana* (cluster 2, Fig. 6B) has a frequency maximum all around the town centre and the industrial zone, and *Cladonia* species (cluster 1, Fig. 6A) is restricted to the extreme periphery of the town. These results may be

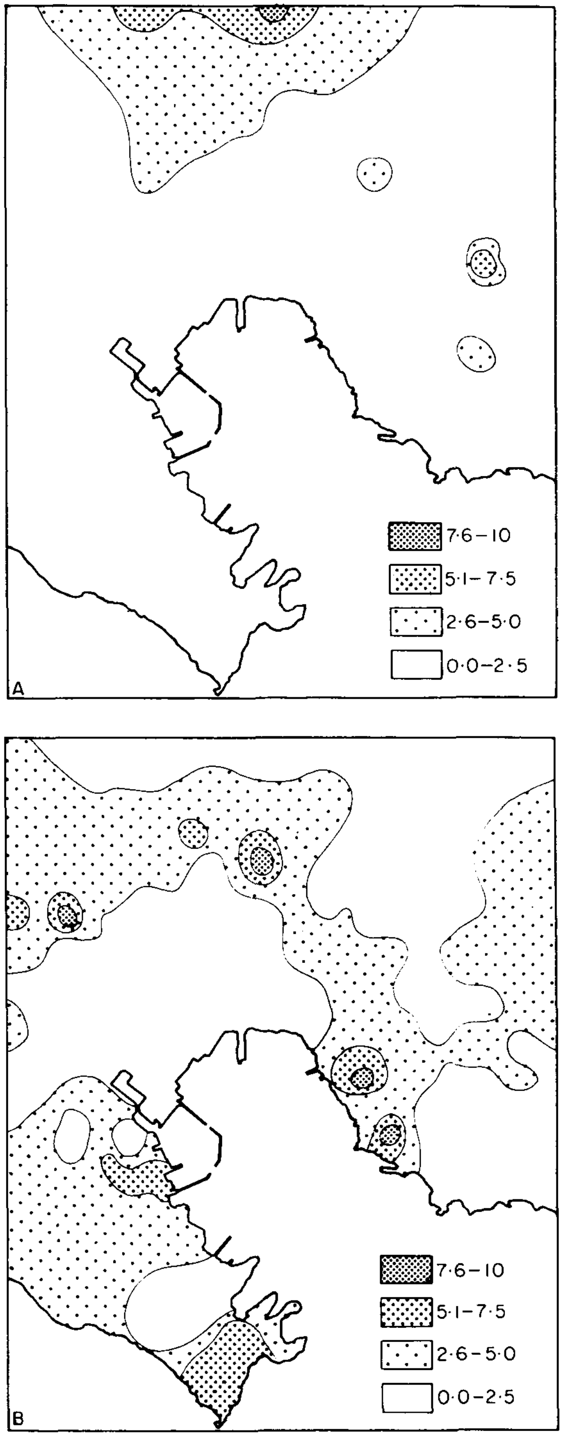

FIG. 6A–B.

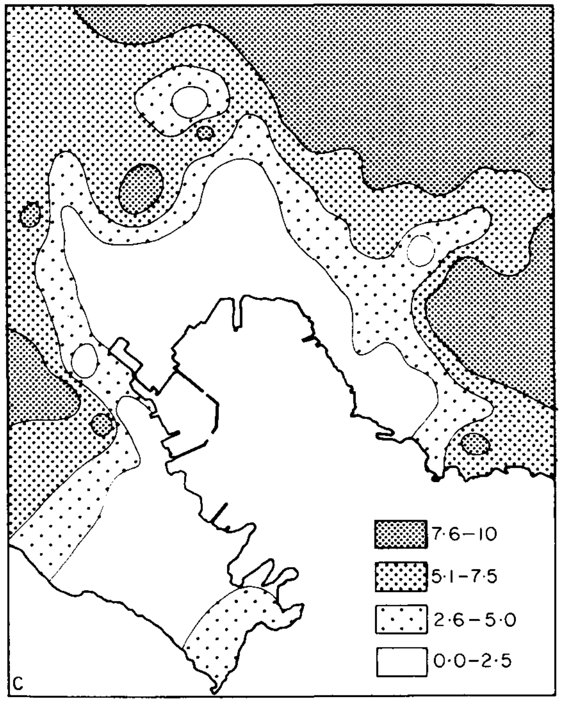

FIG. 6C.

FIG. 6. Distribution maps of three species, one for each main cluster obtained by classification (see Fig. 5); (A) *Cladonia* sp., (B) *Lepraria incana*, (C) *Parmelia caperata*. The shading indicates the mean frequency values of the species within the sampling grid (see text).

interpreted as follows: *Lepraria, Leprocaulon* and *Haematomma* are the less poleophobic species; their relative tolerance to air pollution is probably due to their hydrorepellent, leprose-sorediose thalli; they are low-concurrency species that are favoured by the disappearance of less tolerant lichens. Since their optimum is in the struggle zone around the lichen desert they have not been considered in the calculation of the IAP. *Parmelia caperata*, on the contrary, appears to be the best indicator species; it is widespread throughout the area and its frequency regularly decreases from the periphery towards the town centre. All other species tend to behave as *P. caperata*, but have a more scattered distribution.

To test the correlations between IAP and SO_2 pollution the indices of the eight stations near the recording gauges were plotted against real pollution data, expressed by averages of different parameters such as yearly and seasonal 50° percentiles, 98° percentiles, and average concentrations. In all cases the correlations were statistically significant; the highest correlation is with the average of the 98° percentiles in the last 9 years (Fig. 7). This would suggest that lichens are more sensitive to the frequency of pollution maxima than to average

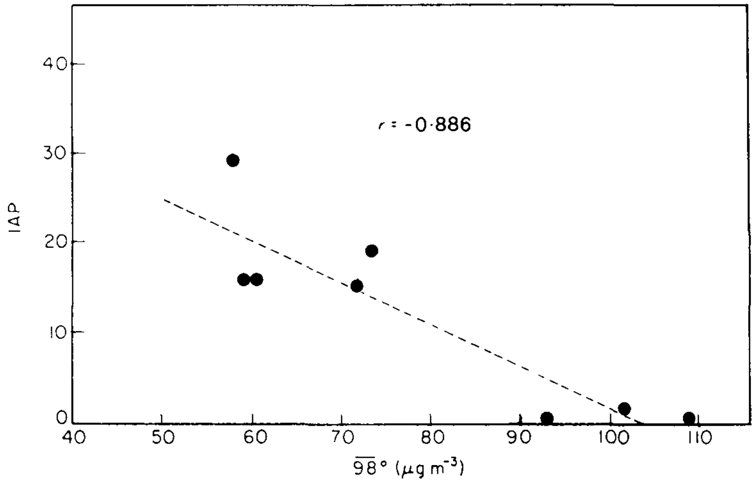

FIG. 7. Correlation between IAP values of the eight stations close to the recording gauges, and average of the 98° percentile in the last 9 years.

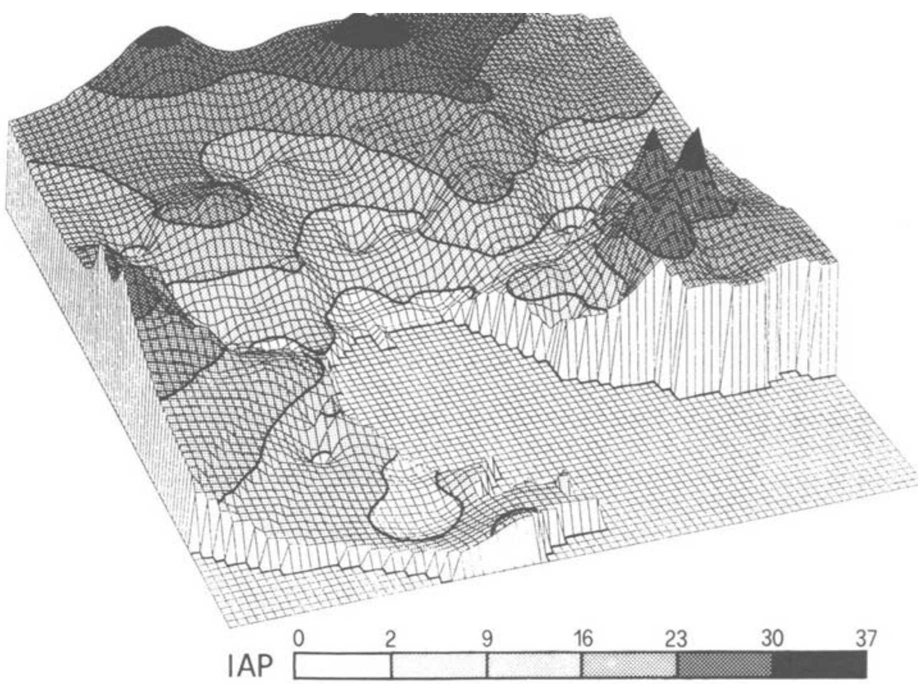

FIG. 8. Three-dimensional IAP map of the survey area. The z-axis = the IAP axis.

values. We could not find any other parameter in addition to air pollution which could be related to the compositional gradient.

The IAP map of the survey area is shown in Fig. 8. It can be transformed into a pollution map using all statistically significant correlations with different pollution parameters by a simple data transformation in the automatic mapping programme. The reliability of such maps depends on the degree of statistical significance of each correlation. The pronounced pollution lobe in the south-western part of the area, which is relatively free of pollution sources, is probably due to the fact that the north-eastern winds tend to turn counterclockwise, assuming a south-western direction, after having crossed the industrial zone and the town centre (Anfossi *et al.* 1979). The automatic mapping programme transforms the original discrete data structure into a continuous distributional model. The three-dimensional model of Fig. 8 can be used to draw ‘ air quality profiles ’ along any transect crossing the survey area.

Conclusions

One of the main problems for a general acceptance of lichens as biomonitors of air pollution is the difficulty of finding a quantitative relationship between lichen data and actual pollution levels. The use of sensitivity scales in computing IAPs values is a possible solution to the problem. This, however, contains elements of subjectivity that are not always accepted by the authorities interested in pollution mapping. Our results show that it is possible to follow a completely objective approach in the use of lichens as biomonitors of SO_2 pollution.

A final consideration concerns the quality of air pollution data obtained from biomonitors. Sometimes biologists are criticized for providing ‘ low quality ’ data, i.e. data laden with a much larger margin of error than the exact measurements of recording gauges. Air pollution, however, is highly variable in time and space; its correct estimate should be always based on a statistical approach, requiring a high density of sampling points, both in time and in space. The high costs of recording gauges is a strong constraint on the density of sampling points; when their density is low, the data have a very low quality, in spite of their apparent precision. Thus the reliability of individual measurement should not be mistaken for reliable estimates of pollution. In La Spezia eight gauges, active for ten years, did not allow the production of a reliable pollution map of the entire area. Our results demonstrate that pollution data from biomonitors may be of very high quality, not only because of the good correlation with direct measurements, but also because of the much higher density of sampling points.

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