*Studia Geobotanica, Vol. 15: 73-89 (1996)*

# BIODIVERSITY OF EPIPHYTIC LICHENS AND AIR QUALITY IN THE PROVINCE OF GORIZIA (NE ITALY)

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**Keywords:** Biodiversity, Italy, Lichens, Pollution.

**Abstract:** In the last six years the north-east Italian plains were intensively studied for air pollution monitoring with lichen biodiversity measures. To date, more than 3.500 relevés of epiphytic lichen vegetation, based on a standard methodology, were carried out in this area. The present study fills a gap in the exploration of the area, presenting the results relative to the province of Gorizia. The study is based on 335 relevés in 104 stations. The relevés are frequency counts of all lichen species in a sampling grid subdivided into ten rectangles. The sum of the frequencies of all species is the Biodiversity Index of each relevé. The average values of Biodiversity Indices of all relevés taken in the same station is the Index of Atmospheric Purity (IAP) of the station, following a slightly modified approach proposed by Swiss authors. The matrices of the 60 lichen species found in the survey area, and of the relevés/stations were submitted to multivariate analysis (classification and ordination): the results show a predominance of nitrophytic *Xanthorion*-species and a transition from *Parmelion* (prevalent in less anthropized areas) to *Xanthorion* vegetation (favoured by agriculture and more resistant to air pollution). Distribution maps showing presence and abundance of eight selected species (*Candelaria concolor*, *Hyperphyscia adglutinata*, *Parmelia caperata*, *P. sulcata*, *P. subrudecta*, *Physcia adscendens*, *Phaeophyscia orbicularis*, *Xanthoria parietina*) are presented and discussed. Automatic mapping programs were also used to map the distribution of the weighed averages of ecological indices associated to each species in each station of the survey area: a map of eutrophication and one of air humidity are presented and discussed. The IAP map of the province is discussed in terms of air quality levels: no extensive lichen desert does occur and IAP values are generally high, but a few restricted areas show some symptoms of air quality worsening, and would be worthy being monitored by instrumental recording.

## Introduction

After the UNESCO Conference of Rio, biodiversity has become a key issue in environmental studies. The widespread use of this term, however, has somehow obscured the efforts for its strict operational definition (see e.g. Whittaker 1972). Today, "biodiversity" is often used in a rather naif sense, as the mere number of taxa occurring in a given Operational Geographic Unit (OGU, Crovello 1981). The quantification of "biodiversity", however, is a much more complex matter. Firstly, it implies a quantitative comparison with OGUs of more or less equal size and similar ecological conditions, a problem which is far from being solved (see e.g. Nimis 1996). Furthermore, biodiversity is also affected by the common/rareness of the species: two OGUs with the same number of taxa obviously differ in terms of biodiversity if in one case the taxa are common and widespread, in the other narrow-ranging and more or less "endemic". Thus, the general distribution of the taxa should also be taken into account, which is not an easy task. Finally, the relative abundance of each species should be considered as well: two OGUs might have the same number of species, but their abundance-frequencies could be very different, and this will affect what we intuitively understand as "biodiversity" of those OGUs.

That lichen "biodiversity" is a good indicator of air pollution is not a recent discovery. The first observations of an impoverishment of lichen floras in polluted environments date back to the half of the previous century (e.g. Nylander 1866). However, it is only after the second World War, especially thanks to the efforts of several west-European and North American authors, that this simple observation was transformed into a scientifically measurable fact, with the formulation of several formulas for calculating Indices of Air Purity (IAP) from lichen data, which led to the present, so widespread and successful use of lichens as bioindicators of air pollution (see e.g. De Sloover 1964, Le Blanc & De Sloover 1970, Hawksworth & Rose 1970, Le Blanc 1971, Ferry *et al.* 1973). One of the authors (P.L.N.) was originally skeptical about many of the IAP indices proposed in the literature, since most of them implied a more or less subjective "quantification" of the "sensitivity value" of each species. His objection was that such "sensitivity values", besides methodological problems concerning their estimate, could well change, for each species, with changing environmental conditions, and that this was very difficult to quantify from an operational point of view (Nimis 1985, 1986). A more convincing approach came from a team of Swiss lichenologists, led by K. Ammann, who tested 20 different IAP formulas in Biel-Bienne, a Swiss town, against direct pollution data (Herzig *et al.* 1985, Liebendörfer *et al.* 1988). These authors surprisingly found that the most predictive measurement was the simplest one: the sum of frequencies of all epiphytic lichen species present on the trunk in a series of quadrants within a sampling grid. This is, in spite of its apparent simplicity, a sophisticated biodiversity index, since such a kind of "IAP" value depends, if the sampling area is constant, on two factors: a) the number of species, b) their frequency-cover. These parameters, in the case of lichens, are long-known to be affected by air pollution. The Swiss approach is superior also at a methodological level, as it does not require any assumption about the "sensitivity" to air pollution of every individual species. These are the reasons why, with some modifications in the sampling strategy (Nimis *et al.* 1990), the "Swiss method" was adopted by the senior author in several case-studies (see e.g. Castello *et al.* 1995), until, in the course of the last decade, it has become almost routine throughout Italy. The main modification adopted by Nimis *et al.* (1990) concerns the size of the sampling area: in the original approach this area is variable, since the sampling grid is adapted to fit half the circumference of each phorophyte. Nimis *et al.* (1990) adopted instead a grid of a fixed size; the main reason for this choice is that frequency counts within grids of different sizes are difficult to interpret in terms of biodiversity/area estimates.

Northeastern Italy, comprising the administrative regions of Veneto and Friuli-Venezia Giulia, is a vast area of 26.217 km$^2$, more or less corresponding to the ancient Republic of Venezia. After the pioneering studies of Nimis on the lichen vegetation of Trieste (Nimis 1985), Udine (Nimis 1986), and the northern part of the province of Vicenza (Nimis *et al.* 1989), this area has become the object of intensive surveys of epiphytic lichen biodiversity related to air pollution monitoring, all based on the same sampling strategy, derived from the "Swiss Method", and hence comparable. The entire Region of Veneto was surveyed in 1991 (Nimis *et al.* 1991), with 662 sampling stations and 2.425 relevés, and re-monitored in 1996 in 180 stations for a total of 750 relevés. The province of Trieste was studied, with the same methodology, in 1993 (Castello *et al.* 1995) on 80 stations for a total of 320 relevés, and the results relative to the province of Gorizia, with 104 stations and 335 relevés are presented here. On the whole, until now 3.495 standard relevés of epiphytic lichen biodiversity were carried out in this area from 1989 to 1995, and c. 70% of the area has been surveyed so far. The aim of this paper is to contribute further to this project, by presenting the data relative to the province of Gorizia, immediately joining that of Trieste (Castello *et al.* 1995) to the west, including 104 stations and 335 relevés. When the provinces of Udine and Pordenone will be completed, this will be one of the largest areas in the world where biodiversity assessments of epiphytic lichens related to air pollution will be carried out with such a high sampling intensity, and with the same methodology.

## Survey area

The survey area, which corresponds to the administrative limits of the province of Gorizia, in northeastern Italy, has a surface of 473 km$^2$, and, geomorphologically, can be subdivided into four main districts (Martinis 1971, Valussi 1971, Cucchi 1984, see Fig. 1a):

1) Collio district - An area of low eocenic hills substratum (max. elevation 275 m), with Flysch as the main lithological, which is the southernmost portion of the Julian pre-Alps. Most of the natural potential vegetation, constituted by acidophytic oak woods, has been largely substituted by cultivations, especially vineyards. However, due to the hilly nature of the landscape, these vineyards are managed in a rather environment-friendly way, without much use of fertilizers and fungicides. In this district there are neither large urban agglomerations, nor important industrial areas.

2) Isonzo Plain district - A lowland area following the course of the Isonzo river, that can be considered as the easternmost part of the Friulian Plain. The main substratum is calcareous alluvial gravel; the albeit poor soils, however, are exploited for agricultural purposes, which has resulted in the

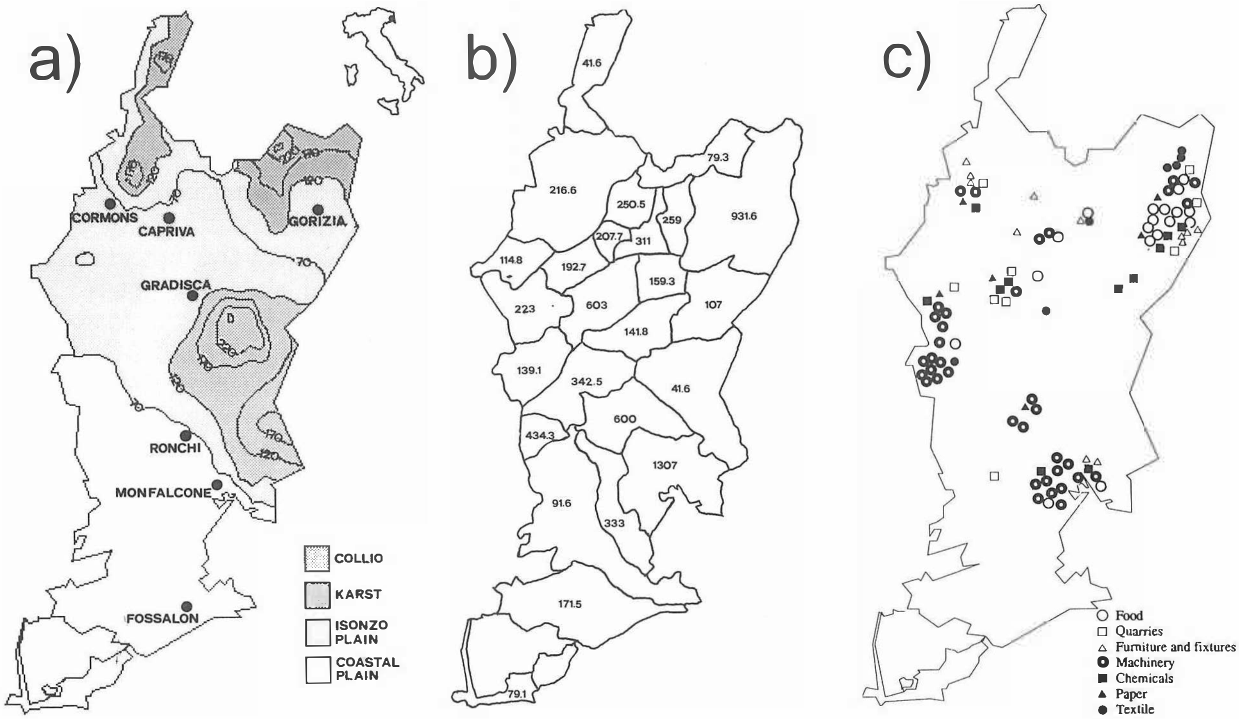


Fig. 1 - Subdivision of the province of Gorizia into four main geomorphological districts: A: Collio, B: Isonzo Plain, C: Karst, D: Coastal Plain; the altitude is indicated by isolines, the main urban centres by circles (Fig. a). Population density (inhabitants/km$^2$) in the municipalities of the province of Gorizia (Fig. b). Location of the main industrial activities in the province of Gorizia (Fig. c).

destruction of most riverine woodlands. This district hosts three important urban centers: Gorizia (38.000 inhabitants), Cormons (7.500 inhabitants) and Gradisca (6.500 inhabitants).

3) Karst district - This is a low calcareous plateau (average elevation: 100 m, max. 275 m) which, to the south-east, borders with the Trieste Karst. Human impact is relatively weak: natural or semi-natural vegetation is prevailing, with open submediterranean woodlands dominated by *Ostrya carpinifolia*, *Fraxinus ornus* and, in more mature stages, by *Quercus pubescens*.

4) Coastal Plain district - This district occupies the southern part of the province, and mainly has fine-textured, clay-silty soils. Most of the area, formerly occupied, especially in its southwestern portion, by swamps, has been reclaimed in the pre- and post-war periods, and natural woodlands have been entirely substituted by intensive cultivations. This district hosts two important centres, which almost constitute a single urban agglomeration, Ronchi dei Legionari (ca. 10.000 inhabitants) and Monfalcone (26.800 inhabitants), and an important industrial area, located east of Monfalcone.

Population density and the location of the main industries are shown in Fig. 1(b-c). The population is concentrated in the municipalities of Gorizia, Gradisca, Ronchi and Monfalcone. The industries are clustered into four main agglomerations, near Monfalcone, Gorizia, Villesse and Romans. The Collio and Karst districts, and the western part of the Coastal Plain are mostly devoid of important industrial activities.

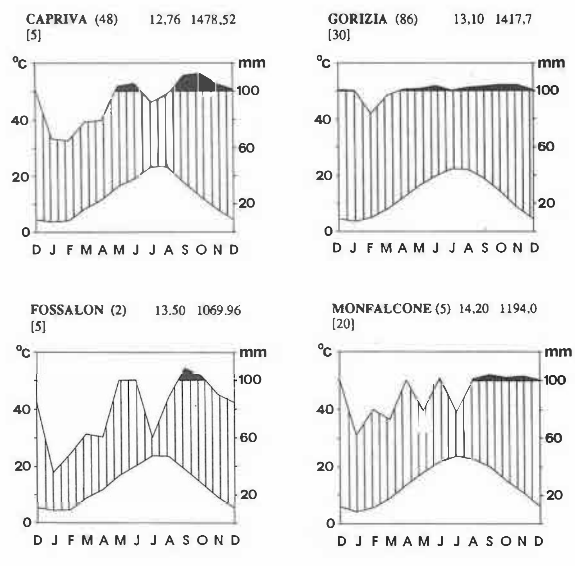


Fig. 2 - Climatic diagrams (according to Walter & Lieth 1960) of four selected localities: Capriva, Gorizia, Fossalòn, Monfalcone.

The climate of the province is conditioned by its morphology: the area is under the mild effects of the sea, and relatively protected by the cold northeastern winds ("Bora"), generally blowing during winter. The climatic diagrams of four selected localities are reported in Fig. 2: average yearly temperature tends to decrease from 14.2 °C at Monfalcone in the south to 12.8 °C at Capriva in the north. Yearly precipitations are relatively high, from 1.000 mm near the coast to more than 1.400 mm in the north, precipitation being most abundant in late spring and early autumn, although there is no dry period in the summer season. Average frequency and speed of the winds for two selected stations are shown in Fig. 3(a,b) (Capriva) and Fig. 3(b,c) (Fossalòn): the prevailing winds are from the north (north-east) and from the east. The influence of the strong, dry, cold Bora-wind during winter is more evident in the southern part of the province (Coastal Plain district). On the whole, however, the survey area enjoys a mild, typically submediterranean climate, without summer drought and extreme climatic conditions during winter.

### Data and Methods

Relevés of epiphytic lichen vegetation were carried out on the following phorophytes: *Tilia* spp.

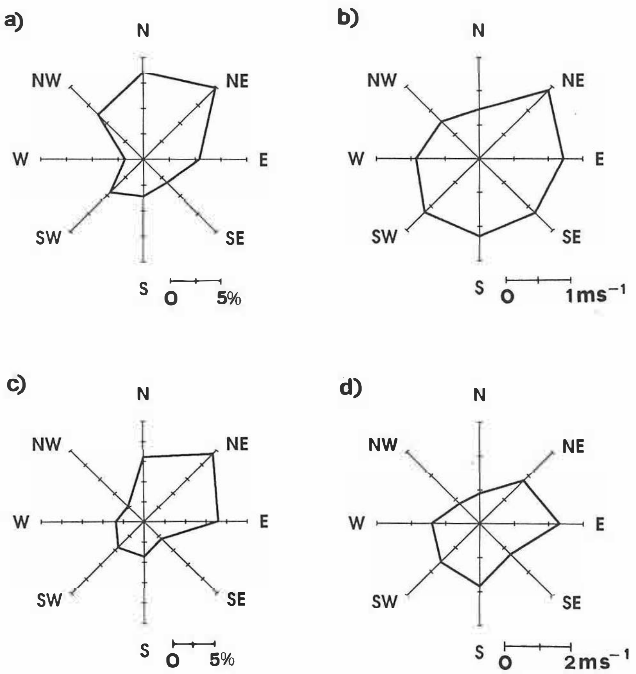


Fig. 3 - Average yearly frequency and average yearly speed of the main winds at the metereological station of Capriva (a, b) and Fossalon (c, d).

(254 relevés), *Quercus* spp. (38 relevés) and *Populus* spp. (43 relevés). *Tilia* was selected as the preferential phorophyte because of its mesotrophic bark with subacid pH (Barkman 1958), and as it was largely used in most of the analogous surveys carried out in NE Italy (e.g. Nimis *et al.* 1989, 1991, Castello *et al.* 1995). The bark of *Quercus*, although tendentially more acid and more oligotrophic, is relatively similar to that of *Tilia* (se e.g. Loppi & Putortì 1995). On the contrary, *Populus* has a subneutral, eutrophic bark, and the data collected on *Populus* cannot be directly compared with those deriving from the other phorophytes. For this reason, an *ad hoc* study was carried out in several stations where *Tilia* and *Populus* were co-existing. The results of this study, which will be published in a forthcoming paper, permitted to obtain a transformation factor for IAP values calculated on *Populus*.

Relevés were carried out on phorophytes satisfying the following parameters: a) inclination of the trunk not higher than 10°, b) circumference larger than 70 cm, c) absence of evident factors of disturbance. A total of 335 relevés was carried out in 104 sampling stations (c. three relevés per station), reported in Fig. 4. The selection of the stations occurred in two steps: a) random choice of ca. 2/3 of the total number of stations, b) preliminary elaboration of the IAP data relative to those stations, c) selective choice of further stations in areas which proved to be not sufficiently covered by the first set of stations, especially in those with a strong spatial variation of IAP values.

Relevés were taken using a sampling grid of 30 x 50 cm, subdvided into 10 rectangles of 10 x 15 cm each. The centre of the grid was positioned in the part of the bole with the highest lichen coverage, at an height of c. 150 cm. A relevé listed all species found within the grid, with the number of grid units in which every species occurred (frequency value) being computed. The sum of the frequency values of all species is the Lichen Biodiversity Index (LBI) of the relevè. The average of LBI values of the relevés of each station is the LBI of the station (henceforth called IAP index).

The values of the ecological indices proposed by Wirth (1980), transformed into an ordinal scale as suggested by Nimis *et al.* (1987), were associated to each species. The weighed averages of these values per relevé, using presence-absence data, were used to characterize the ecology of the clusters of relevés, and, in the case of stations, for mapping purposes (see results section).

The matrix of species and relevés (the latter reduced to 317, because some of them were within lichen desert areas), and that of species and stations, were submitted to numerical classification, in order to detect clusters of species with similar ecology, and clusters of floristically similar relevés/stations. The dendrogram of relevés was obtained on the basis of the Coefficient of Correlation, that of stations on the basis of Euclidean Distance. Minimum Variance was used as a clustering algorithm. The matrix of species and relevés was further submitted to Reciprocal Ordering ordination, to detect possible ecological gradients, and to extract a limited number of indicator species. Multivariate analyses were carried out with MULVA (Wildi & Orlóci 1984).

All isoporic maps were obtained by computerized automatic mapping, using the package SURFER (Golden Software Inc., Golden, Colorado). These programs are based on a grid, whose mesh size depends on the minimum and maximum values of the input data. The interpolation method utilized to create a regular grid starting from points (stations) is based on the values of the ten nearest stations. The influence of a given station on a grid point is inversely proportional to their distance.

Nomenclature follows Nimis (1993).

## Results

Two data sets are available for this study: the frequencies of all lichen species in the 335 relevés (plus the biodiversity indices of the relevés), and the average frequencies of all species in the 104 stations (plus the IAP indices of the stations). The former have been analyzed in order to give information on the lichen vegetation of the survey area, the latter were used for mapping purposes.

### *Analysis of the relevés*

Altogether, 60 species of lichens were found in the survey area (see Tab. 1), a number which is in good agreement with analogous studies in areas of comparable size and ecological conditions (Nimis *et al.* 1989). The dendrogram of the 317 relevés is schematically shown in Fig. 5, the ordered table is reported in Tab. 1, and the geographic location of the clusters of relevés is shown in Fig. 6 (a,b). In the following, the five main clusters of relevés resulting from the classification will be briefly commented on.

Cluster 1 (71 relevés, 43 species): this cluster is characterized by the highest frequency and / or abun-

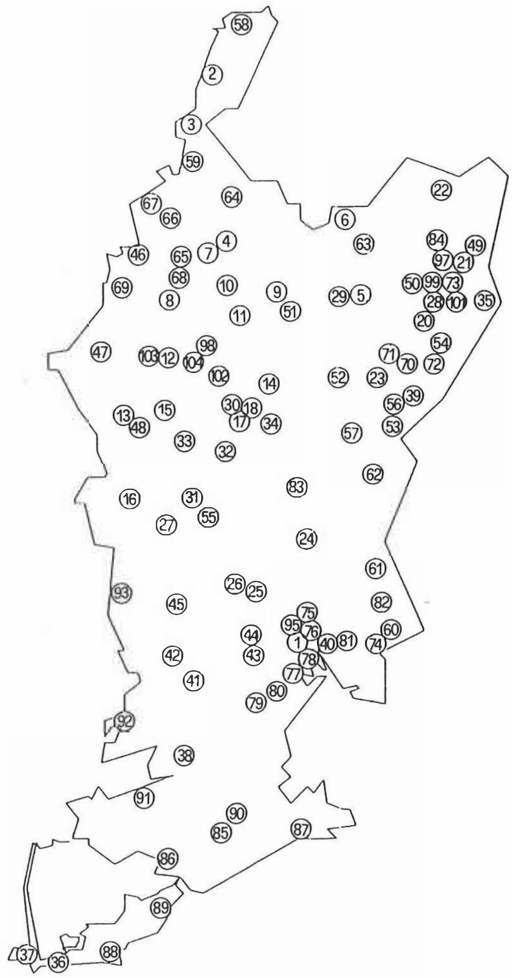

Fig. 4 - Location of the 104 sampling stations in the survey area. The stations are numbered as in Tab. 2.

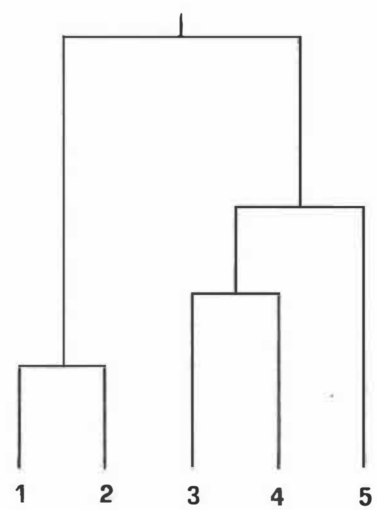


Fig. 5 - Dendrogram of the relevés, based on the data of Tab.1, showing only the five main clusters (minimum variance clustering, correlation coefficient).

Tab. 1 - Frequency of species in the relevés. Numbers refer to frequency counts within the sampling grid. The frequency value of 10 is reported as 9 for reasons of space.

| No. | Species | | Relevés |
|---|---|---|---|
| | GRUPPO DI RILIEVI | | .333333333333333333333333333333333444444444444444444444444444444444444444444444444444444444444444444444444\|5555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555 |
| | RILIEVO N. | | .212  222 2 221 12111  23223221221112111 1 111 22222221 111112 1322222222321 2  \|2 11131 1  1 111  11  3111  3 2111222222221 22321 22222 221  222111  213321332 |
| | | | .71222333552123855322215075063742533379 3 2 652 98877736762322978098595366055484843\|58800058588564439955880086909206199788998891212618838586628443588626161017007 |
| | | | .75842390030904081097192560806836021570335409310895431271492055709378872119585109\|5416741725638018877632255409333478219204314149443064474843891086325375609397 68 |
| 57 | Usnea subfloridiana | 1 | . |
| 54 | Pseudevernia furfuracea | 1 | . |
| 37 | Parmelia saxatilis | 1 | . |
| 60 | Parmelia pastillifera | 1 | . |
| 17 | Hypogymnia tubulosa | 1 | . |
| 16 | Hypogymnia physodes | 1 | .  \|  1   5 |
| 52 | Physcia tenella | 1 | .  \|  415 |
| 46 | Phlyctis argena | 1 | . |
| 29 | Lepraria sp. | 1 | . |
| 35 | Parmelia exasperatula | 1 | .   2   2  \|  1   9 |
| 38 | Parmelia subaurifera | 1 | .   133 |
| 12 | Evernia prunastri | 1 | .   1  1 |
| 40 | Parmelia sulcata | 1 | .   1   3  1  \|  1 |
| 34 | Parmelia caperata | 1 | .   551   1   11  121111  \|  2 2   1   15   2   9 |
| 39 | Parmelia subrudecta | 1 | .  4   2112  1  3 1   1   1  \|  94 11   32191311   8111   322 |
| 6 | Candelaria concolor | 3 | .  99993991979939   993   794599  9389 539979   999278412199993959999699399\|29999999999999 989899998991999 51   11 9999999999995999 99   9969856  85 |
| 7 | Candelariella reflexa | 3 | .2964558273896392   5 8   7   3   57399 64  \|  6   1   79999995   99 1943635 |
| 47 | Physcia adscendens | 3 | .6999998999983969   96594995999999999 99979999989   99599 99999996998999997999\|  2   98976 3899499199   99449299959989899 519999   97 59  9 |
| 15 | Hyperphyscia adglutinata | 4 | .999998   9999998969999 9692   9   37   1   9999 995999 297699979\|978589998955964 4   99999767   9889799999 999   8859993356999 99 22  496   9 |
| 28 | Lecidella elaeochroma | 3 | .   9885   979999999996924299718856993 99957 5199997424499979 71299\|  38  332268  98   7   1   9   1 |
| 36 | Parmelia glabratula | 1 | .   1   2   1   61 |
| 9 | Candelariella xanthostigma | 3 | .   9   92412   1  \|  22   5 3 |
| 24 | Lecanora pallida | 3 | . |
| 25 | Lecanora pulicaris | 3 | .   1 |
| 3 | Buellia punctata | 3 | .  \|  1 |
| 41 | Parmelia tiliacea | 3 | .   2 1   2   1 21  \|  14 |
| 48 | Physcia aipolia | 3 | .   1   11   3  31  \|  13 |
| 10 | Catillaria nigroclavata | 3 | .   2 |
| 19 | Lecanora carpinea | 3 | .   3   2  223  6   2 1   21  \|  31 |
| 43 | Pertusaria albescens | 2 | .   4 |
| 21 | Lecanora chlarotera | 3 | .   1  11123   623211  6   3   1111   57\|  2   4 |
| 14 | Heterodermia obscurata | 2 | . |
| 56 | Rinodina sophodes | 3 | .   1   9   1 |
| 27 | Lecanora symmicta | 3 | .   212 |
| 30 | Normandina pulchella | 2 | .  \|  1   3 |
| 50 | Physcia clementei | 2 | . |
| 42 | Parmotrema chinenese | 2 | .  \|  1 |
| 26 | Lecanora strobilina | 2 | .   1 |
| 8 | Candelariella vitellina | 4 | .   1   4 |
| 18 | Lecanora allophana | 4 | .   2   414 5  \|  2   12 |
| 59 | Xanthoria parietina | 4 | .2 1816 5   4   6 79   9991 37929114562175959 42   28 39534\| 5   92   98799869   295929914 |
| 51 | Physcia orbicularis | 4 | .   2   5  999955   89998999512  9   199911\|9993969959975999 9  99  992928994999 998899599999979 98889593 199999899299 992 |
| 1 | Arthonia radiata | 4 | .   9  6  43   5   1 2   2   2  \|  29888   1135  1   1   3 |
| 45 | Phaephyscia chloantha | 4 | .   3  \| 919596192 958939912656922 6 6814   5 |
| 49 | Physcia biziana | 4 | .   11222115 1  \|  2   99125 |
| 53 | Physconia grisea | 4 | .   6  \|  5  6 |
| 33 | Parmelia acetabulum | 3 | .   1 |
| 5 | Caloplaca holocarpa | 4 | .   2   1   49 |
| 58 | Xanthoria fallax | 4 | .  \|58   2 |
| 31 | Opegrapha atra | 4 | .   1  \|  5 |
| 2 | Arthrosporum populorum | 3 | .   1   51  \|  1  4 |
| 20 | Lecanora conizaeoides | 4 | .   3  \|  3   1 |

| GRUPPO DI RILIEVI | | 1 | 2 | 3 |
|---|---|---|---|---|
| RILIEVO N. | | 11 11 111 11121 3 1 1 12 3111 22 2 2 11 1 21 1 1111 | 2222211111121212 212122 | 2322 2 2 222 2 1 22212121 1 21213 313 1 1 121 21212 |
| | | .333366443 77116606774174723553931549 4 15871128851774241760090700997441 | 4222211400911191496963694944 | 9547761927361 600305170002464865064909121311154711732 4 95141 |
| | | .768510424854434813018722375630211835429491131867220726009929090361835 | 66986521187341382647693892245 | 495646261226855612257395468990518277356776565296801759774 6776 |
| 57 Usnea subfloridiana | 1 | .1122 374 2 1 1 1 | 2 | |
| 54 Pseudevernia furfuracea | 1 | .125 5 6 1 | 1 | |
| 37 Parmelia saxatilis | 1 | . 2 1 1 | | |
| 60 Parmelia pastillifera | 1 | . 3 7 11 7 | 2 | |
| 17 Hypogymnia tubulosa | 1 | .99999893 | | 4 |
| 16 Hypogymnia physodes | 1 | . 3 1195 92 5 26 8 2 1 1 3 | 698 2 2 | 3 1 |
| 52 Physcia tenella | 1 | .9999 4 8 4 9 4 | 3 7 | 5 9 5 964 |
| 46 Phlyctis argena | 1 | .1 5 1 | 723 9 | 1 |
| 29 Lepraria sp. | 1 | . 94 12 8 26 911 2 | 3 9999551 6136276 | 3332 1 1 |
| 35 Parmelia exasperatula | 1 | .99796267 2 69515 927 9 7698 3212413 | 2 | 1 91 2 5 4 31 1 |
| 38 Parmelia subaurifera | 1 | .7893 599796 362 2 31242 6149137184 | 957 | 1 4111742 |
| 12 Evernia prunastri | 1 | .4968255211 1 114 2 1 1 4 3 3 1 3 | 22 1 31 221 | 1 1 |
| 40 Parmelia sulcata | 1 | .99798467879615 1352154122138513451725212121111439237171 91 8 539 3 1 | 621 8 23999597 544 1 | 8 2 21 1 1 |
| 34 Parmelia caperata | 1 | .71 412114911991123 222 2 1111 16 56 22 135 9951112142221 1 6 | 999997 999 988987995173235 | 12164223211 62192215924929312 2 214 15281937 12 9 |
| 39 Parmelia subrudecta | 1 | .825 139157159 11 215254 63537 39 2 167 1 2 719694552113372264 7 | 99991 151937556 192394142 | 7 82456 3 3 11347623391969194993926 9311263 |
| 6 Candelaria concolor | 3 | .9999 8 966 93945999996 9999999977947 1 99919999999394699738619734999 9 | 9582 4 9 | 99999959999954964989839 3 698949799999999 99699598399999 8996929 |
| 7 Candelariella reflexa | 3 | .999289 99995999996997799 9 97891 5994295 9 99 798979499939979937677 | 9986998 9 5 | 299356 6999499942 9959 9 9495689967639 3249 |
| 47 Physcia adscendens | 3 | . 92999969 99629999979999999899 3 97839999999999999 89993933 94 | 154 299176 92 5949995 | 899579989 99991999999989 99999879985999939299994 9949 9999 |
| 15 Hyperphyscia adglutinata | 4 | . 15 7 9 9218999 99997 969 99 59798 9 9289552 99 | 959 | 99999993969797759939869997 9 1 9659999999987 99999599999779 |
| 28 Lecidella elaeochroma | 3 | . 4 5 69 9 6 994995419889252862739892396769795919995379 8 | 2 6 532 557856997 9 | 266827949 26176959959 173 9 5 99 889739999 |
| 36 Parmelia glabratula | 1 | . 35 659177 3 9 8 9 | 55 95166959 99 9 5699 | 11 1 7 15 |
| 9 Candelariella xanthostigma | 3 | . 9 2 9 143169 1 | 99 69899699999 | 1237 99493 4 1 3999 1 |
| 24 Lecanora pallida | 3 | . 3 5 | 1 | |
| 25 Lecanora pulicaris | 3 | . 2 1 | | 6 |
| 3 Buellia punctata | 3 | . 44 2 5 | 3 | 161 |
| 41 Parmelia tiliacea | 3 | . 1 2 21 213 22 2 1 2 | 1 3 11 2 | 2 |
| 48 Physcia aipolia | 3 | . 7 1 22 | 2 1 | |
| 10 Catillaria nigroclavata | 3 | . 9 | | 9 |
| 19 Lecanora carpinea | 3 | . 2 8 2 | | 1 21 4 |
| 43 Pertusaria albescens | 2 | . 2 | 99 3 | |
| 21 Lecanora chlarotera | 3 | . 3 13 22111123 | 7 1 1 1 | 1 |
| 14 Heterodermia obscurata | 2 | . | 1 | 2 |
| 56 Rinodina sophodes | 3 | . 8 | 1 | |
| 27 Lecanora symmicta | 3 | . 1 | 2 1 | |
| 30 Normandina pulchella | 2 | . 2 | 714312 8 8 8 | 1 29 |
| 50 Physcia clementei | 2 | . | 9563 3 | 9 5 3 9 9 |
| 42 Parmotrema chinenese | 2 | . | 11 1 1 2 5 | 1 |
| 26 Lecanora strobilina | 2 | . | 21 1 31 4 | 3 74 54 |
| 8 Candelariella vitellina | 4 | . 7 3 | | 1 |
| 18 Lecanora allophana | 4 | 21 5 | 1 | 2 34 2 12 |
| 59 Xanthortia parietina | 4 | . 2 7 2 319 2 1 | | 692 1 1 118 72 2 3 5559 |
| 51 Physcia orbicularis | 4 | . 251 198 7997 9959922 6823122 5 739 9999 | 3 | 77992723199 2 3 7 |
| 1 Arthonia radiata | 4 | . 3 1 7263281 5 | 3 8 | 7 9 |
| 45 Phaephyscia chloantha | 4 | . 9 9 6 99 7 | | 5 4 9 |
| 49 Physcia biziana | 4 | . 4 | 1 | 5 |
| 53 Physconia grisea | 4 | . 21 | | 6 |
| 33 Parmelia acetabulum | 3 | . | | 1 1 |
| 5 Caloplaca holocarpa | 4 | . | | 1 |
| 58 Xanthoria fallax | 4 | . | | |
| 31 Opegrapha atra | 4 | . | | |
| 2 Arthrosporum populorum | 3 | . | | |
| 20 Lecanora conizaeoides | 4 | . 2 | | 2 |

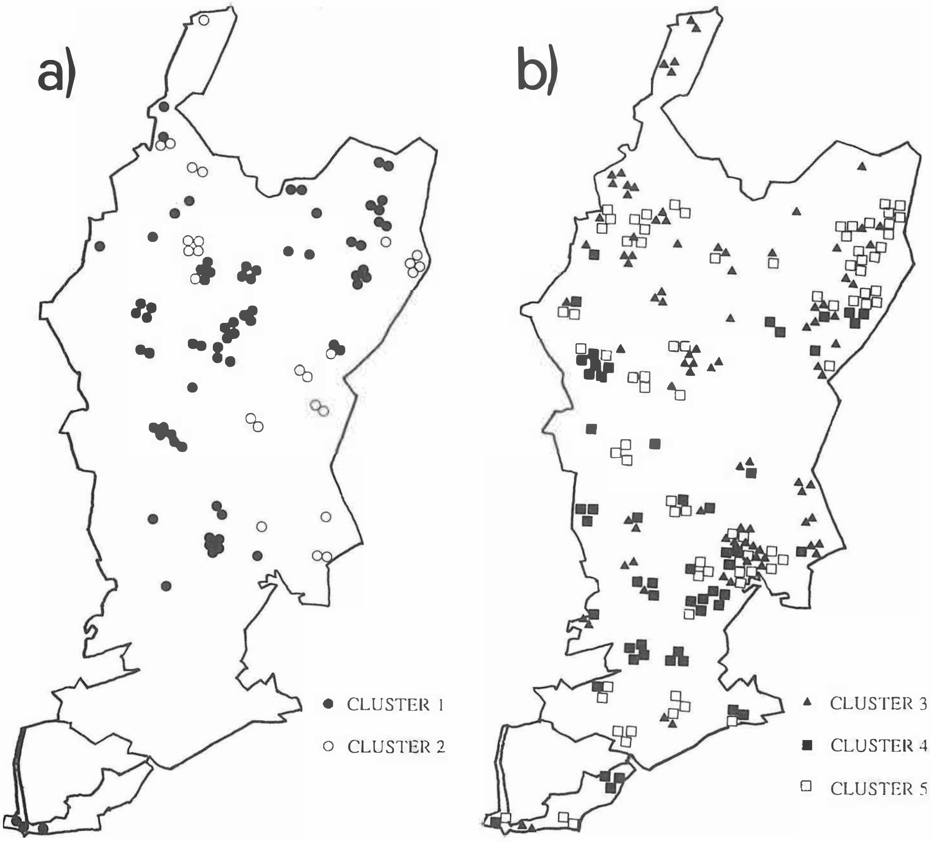


Fig. 6 - Distribution of the 5 clusters of relevés in the survey area: a) clusters 1-2, b) clusters 3-5.

dance of a set of acidophytic species, such as *Evernia prunastri*, *Hypogymnia tubulosa*, *Hypogymnia physodes*, *Parmelia pastillifera*, *Parmelia saxatilis*, *Parmelia subaurifera*, *Parmelia sulcata*, *Pseudevernia furfuracea*, *Usnea subfloridana*, which are scarcely represented in the other clusters. Lichen Biodiversity Indices are the highest of the whole data set (Fig. 7). Most of the relevés were taken on the northern side of the boles (Fig. 7). This lichen vegetation, which is clearly related to the *Parmelion*-alliance (Barkman 1958, Nimis 1982), is practically absent from the Coastal district (Fig. 6a).

Cluster 2 (26 relevés, 36 species): floristically similar to cluster 1, this cluster differs in the scarcity of several strictly acidophytic species, in the presence of a set of suboceanic species indicative of relatively high air humidity, such as *Lecanora strobilina*, *Normandina pulchella*, *Parmotrema chinense* and *Physcia clementei*, and in a lower frequency of some common nitrophytic lichens such as *Hyperphyscia adglutinata*, *Candelaria concolor* and *Candelariella reflexa*, the latter being substituted by the less nitrophytic *Candelariella xanthostigma*. Also in this case LBI values are generally high (Fig. 7). Most of the relevés were taken on the northern part of the boles (Fig. 7). Like in the previous case, also the relevés of cluster 2 are absent from coastal areas (Fig. 6a), their distribution being restricted to the northern and eastern parts of the survey area (Collio and Karst districts).

Cluster 3 (89 relevés, 40 species): this cluster marks an evident vegetational transition: it is characterized, as the following clusters 4 and 5, by the dominance of a few species, most of which are characteristic of *Xanthorion*-vegetation. *Parmelia caperata* and *Parmelia subrudecta*, however, are still present with high frequency here, so that cluster 3 could be considered as transitional between *Parmelion* and *Xanthorion*. On the whole, the floristic composition corresponds well with that of

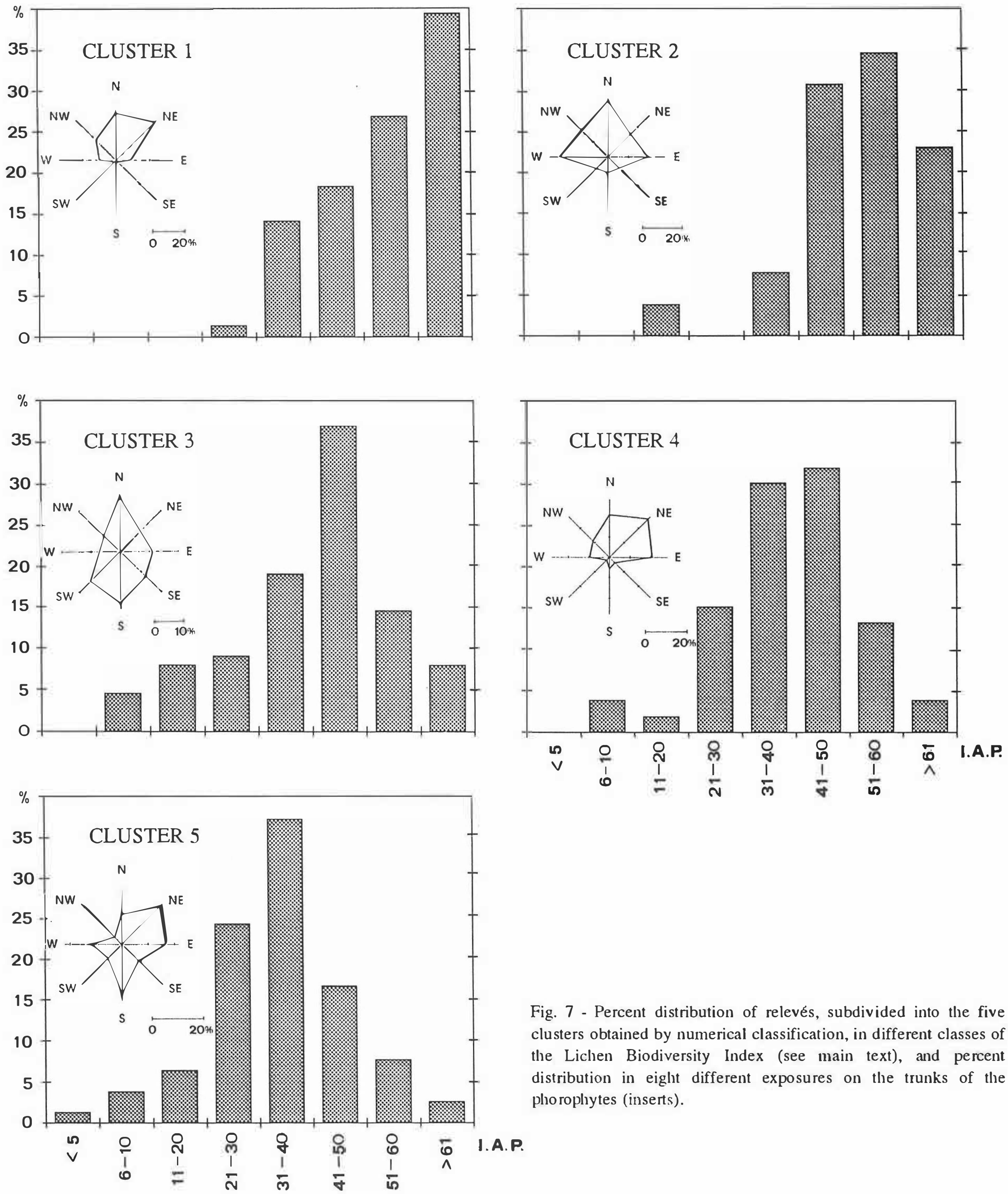


Fig. 7 - Percent distribution of relevés, subdivided into the five clusters obtained by numerical classification, in different classes of the Lichen Biodiversity Index (see main text), and percent distribution in eight different exposures on the trunks of the phorophytes (inserts).

the "*Physcietum elaeinae candelariosum*" described by Nimis & De Faveri (1981), the most common epiphytic synusia on isolated trees in the plains of northeastern Italy (see also Nimis *et al.* 1989, 1991). The LBI values (Fig. 7) tend to be lower than those of the previous clusters. The location of the relevés around the boles is much less selective, many relevés being located also on the south-exposed sides of the trunks (Fig. 7). Geographically, the relevés are distributed throughout the survey area, with higher frequency in its northern, central and eastern parts (Fig. 6b).

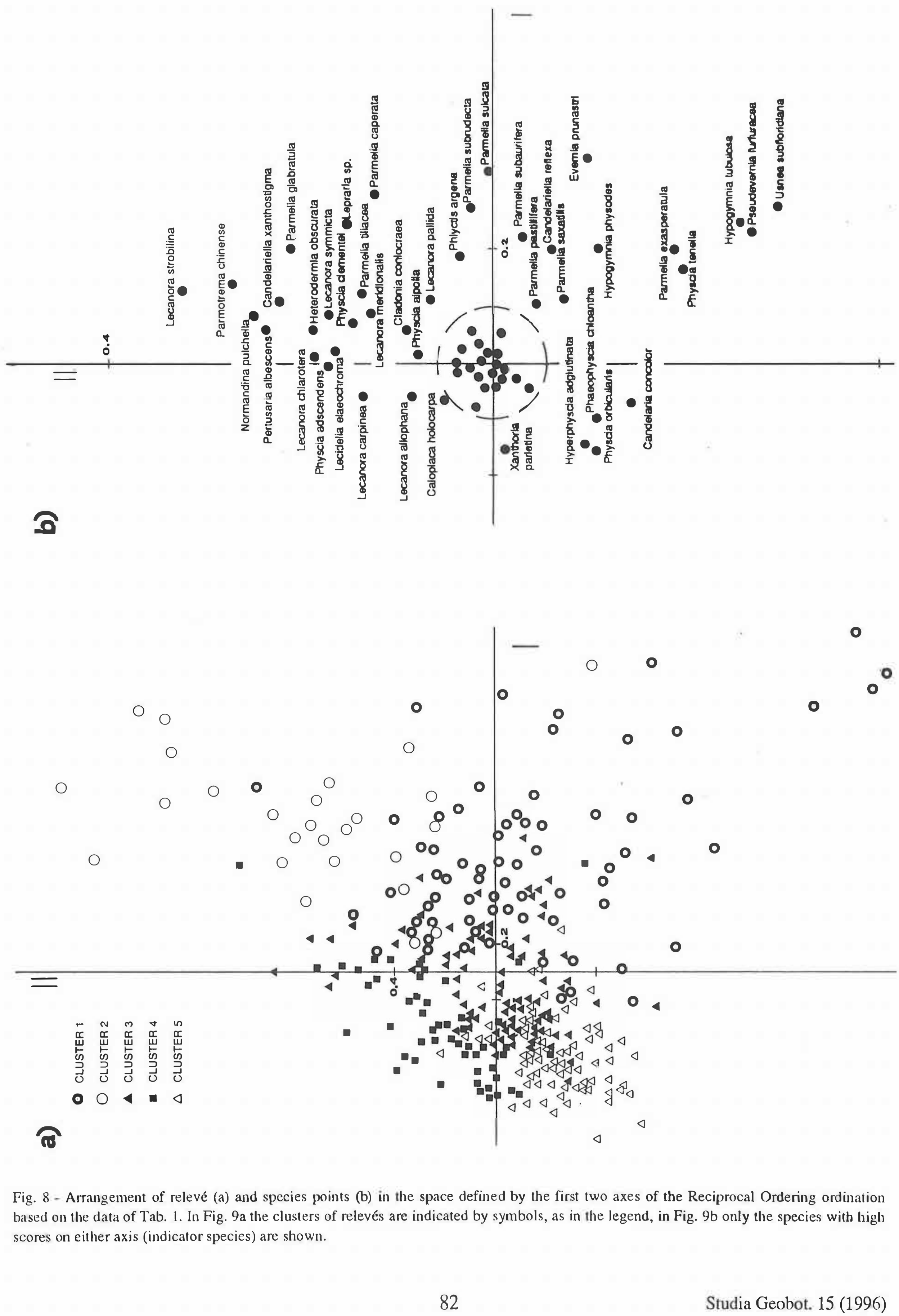


Fig. 8 - Arrangement of relevé (a) and species points (b) in the space defined by the first two axes of the Reciprocal Ordering ordination based on the data of Tab. 1. In Fig. 9a the clusters of relevés are indicated by symbols, as in the legend, in Fig. 9b only the species with high scores on either axis (indicator species) are shown.

Cluster 4 (53 relevés, 35 species): also this cluster has a prevalence of *Xanthorion*-species. It differs from the previous one by the lesser incidence of the nitrophytic species *Candelaria concolor* and *Hyperphyscia adglutinata*, which are substituted by *Phaeophyscia orbicularis* and *Physcia biziana*. On the whole, this is a slightly less nitrophytic variant of cluster 3. Biodiversity tends to be slightly lower than in cluster 3 (Fig. 7), and most relevés are from the northern side of the boles (Fig. 7). The relevés of this cluster are most frequent in the western part of the province, and in the Coastal Plain district (Fig. 6b).

Cluster 5 (78 relevés, 30 species): most species of *Parmelion* are absent from this cluster, which is dominated by a few *Xanthorion*-species, such as *Candelaria concolor*, *Phaeophyscia orbicularis* and *Physcia adscendens*. This is the cluster with the lowest Lichen Biodiversity Indices (Fig. 7). The relevés were taken both at the south and north sides of the boles, with a prevalence of NE and S positions (Fig. 7). The relevés are distributed throughout the survey area, but tend to be concentrated near the largest urban agglomerations and industrial areas (Fig. 6b), which suggests that their floristic composition could be affected by air pollution.

The Reciprocal Ordering ordinations of relevés and species are shown in Fig. 8 (a,b). In the ordination of relevés (Fig. 8a), the first axis clearly separates clusters 1 and 2 (positive scores) from clusters 4 and 5 (negative scores), cluster 3 being intermediate. The second axis mainly separates cluster 1 (negative scores) from cluster 2 (positive scores). This arrangement of points is related to LBI values, which show a clear trend along the first axis (Fig. 9), relevés with positive scores tending to have higher values than those with negative scores. The ordination of the species (Fig. 8b) shows that nitro-, xero- and heliophytic *Xanthorion*-species, which in this part of Europe are generally more tolerant to air pollution (see Nimis 1985, 1986), have negative, or low positive scores on the first axis, while most acidophytic, relatively hygrophytic and less heliophytic, more pollution-sensitive *Parmelion*-species have high positive scores. The arrangement of the relevé points along the first axis of Fig. 8a can be interpreted as a gradient of decreasing nitrophytism and increasing acidophytism, which is paralleled by an increase of the Lichen Biodiversity Index, and by a transition from *Xanthorion*- to *Parmelion*-vegetation. It could be also interpreted as a gradient of decreasing anthropization and decreasing air pollution (see later). The second axis

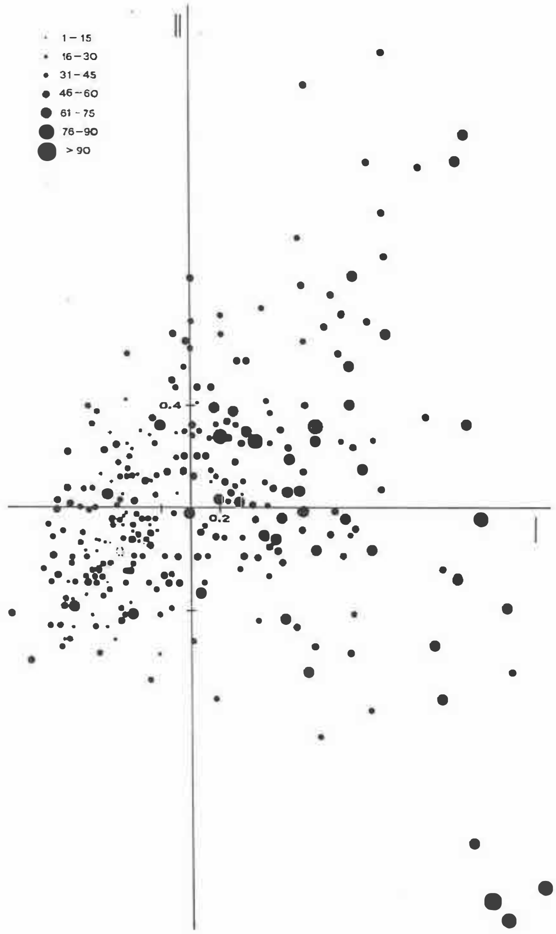


Fig. 9 - Distribution of the Lichen Biodiversity Index in the ordination of relevés of Fig. 8a. The values of the index are represented by dots of increasing size, as in the legend.

mainly accounts for the variation in the two most species-rich clusters (1 and 2), and reflects a gradient in air humidity, limited to clusters 1 and 2: the relevés with positive scores (cluster 2) are those with the highest incidence of relatively more higrophytic lichens, those with negative scores (cluster 1) have the highest incidence of more xerophytic species.

*Analysis of the stations*

The average frequency data of all species in the 104 stations were also submitted to numerical classification. The dendrogram of the stations is in Fig. 10, and the ordered matrix - in which the species are also arranged according to the results of a numerical classification (not shown) - is reported in Tab. 2. Four main groups of stations are formed (1-4). Group 1 is characterized by a high incidence of *Parmelion*-species. Group 2, while maintaining

Tab. 2 - Average frequency values of the species in the 104 stations, which are numbered as in Fig. 2.

| | | | | | | |
|---|---|---|---|---|---|---|
| CLUSTER N. | | | .111111111111111 | 2222222222 | 333333333333333333333333 | 4444444444444444444444444444444444444444444444444444444 |
| STATION N. | | | . 1 | | 1 1 | |
| | | | .12511 6210 373 | 3765585658 | 1611 099446758462527681 0 | 9 483492531296323365474777 8 632 482148 737928894599 |
| | | | .201453320361365 | 5446839272 | 9118223275022019554969347 | 7280641027987439754483650941888497668181371765003566 |
| 17 | Hypogymnia tubulosa | A | .93 4 | | | 1 |
| 54 | Pseudevernia furfuracea | A | .211 | 1 | | |
| 24 | Lecanora pallida | A | . 3 3 | 1 | | |
| 60 | Parmelia pastilllifera | A | .1 21 4 1 | | 1 | |
| 57 | Usnea subfloridiana | A | .1114 | 1 | | 1 |
| 29 | Lepraria sp. | A | . 3 123 13 1 | 93 2 56 1 | 131 | 1 4 2 |
| 3 | Buellia punctata | A | . 4 | 1 | 1 1 | 2 1 1 |
| 50 | Physcia clementei | A | . 9 | 2 3 | 1 | 2 1 |
| 52 | Physcia tenella | A | . 5 9 1 | 1 2 | 4 | 2 5 35 12 |
| 16 | Hypogymnia physodes | A | . 44 1 36 | 1 1 | 1 2 1 | 1 1 1 12 |
| 12 | Evernia prunastri | A | .72 211 11 11 | 1 11 1 | 11 11 | 1 1 1 1 |
| 35 | Parmelia exasperatula | A | .9347 2 4 9 3 | 11 | 1 1 1 | 2 1 221 2 1 1 2 |
| 38 | Parmelia subaurifera | A | .724 592 58 9 | 1 2 | 2 12 1 31 | 1 1 2 1 1 3 3 |
| 40 | Parmelia sulcata | A | .9337571426 41 9 | 9141 55121 | 3 33 11 1112 | 411 1 1 11 1 2 2 211 1 1 |
| 34 | Parmelia caperata | A | .32114998959211 | 7483764997 | 15131211113 12122 1 | 214 1 21111112331 12 13 11 3 1 1 5 |
| 39 | Parmelia subrudecta | A | .4234875896521 | 5112964352 | 322212 1111 1 112 | 7872811 13574 21 1 41 11 11111111 1 1 2 |
| 7 | Candelariella reflexa | A | .897769779999999 | 83 74 | 974767 142 25616 2 5 | 84 4 527979356599126 11214 176235 1 32 1 1 |
| 6 | Candelaria concolor | C | .947599487956149 | 2 37 12 4 | 9385999999998969697549 | 99999789999798991898274799959699689989999119 8 |
| 28 | Lecidella elaeochroma | C | .1 47969 1 8 2 | 391727633 | 87577969688879997996597798 | 1 32 1 6 4 351 3 4 6 11 6245 1 3179 14 1 |
| 15 | Hyperphyscia adglutinata | C | .41343 62454159 | 93 7 | 79499999979 4232698859 | 35997599769999999999 2 5215 5345588919968996 7996 1 |
| 47 | Physcia adscendens | C | . 699899 53 9979 | 8636 6444 | 9799899999898996999999 5 | 9729213372999455 96233 99999999997799299 59 13 152 |
| 51 | Phaeophyscia orbicularis | C | . 1 5 1 136 | 6 1 1 | 3 2 15 111 423 22 | 81 95734 8 5 15 999899 263765868999999 14 799191 41 |
| 41 | Parmelia tiliacea | C | .1 1 1 11 | 1 2 | 1 1 1 11 | 1 1 1 11 1 11 11 |
| 36 | Parmelia glabratula | B | . 51 32 1 | 6 7 7969 | 1 4 1 1 | 2 3 4 21 21 1 11 |
| 46 | Phlyctis argena | B | .2 1 | 571 | | 3 |
| 37 | Parmelia saxatilis | B | . 11 | 3 | 1 | 1 |
| 42 | Parmotrema chinense | B | . 1 | 1 31 1 | | 1 1 |
| 14 | Heterodermia obscurata | B | . 1 | 1 | | |
| 30 | Normandina pulchella | B | . 1 3 | 32 4 3 | 4 1 | 2 1 |
| 25 | Lecanora pulicaris | C | . 2 1 | | 2 1 | |
| 26 | Lecanora strobilina | B | . 4 | 2112 1 | 2 | 3 |
| 43 | Pertusaria albescens | B | . | 1 9 | 3 | |
| 27 | Lecanora symmicta | B | . | 1 1 1 | 1 11 | 1 |
| 5 | Caloplaca holocarpa | B | . | 1 | 1 2 | 1 |
| 9 | Candelariella xanthostigma | B | . 1 1 | 9 7993598 | 3362 16 2 | 1 1 12 1 11 3 2 11 1 1 |
| 48 | Physcia aipolia | C | . | 1 1 1 | 1 2 1 | 1 1 1 1 |
| 18 | Lecanora allophana | C | . 1 | 1 | 1 23 11 | 1 2 1 1 1 |
| 21 | Lecanora chlarotera | C | . 1 1 | 1 13 | 11 1 11121 1 45 | 11 1 1 1 |
| 1 | Arthonia radiata | C | . 11 | 1 | 1 42 1 2 1 2 1 | 1 3 21 2 9 1 1 1 2 1 8 |
| 59 | Xanthoria parietina | C | . 1 | 1 | 2 6653 3 1 111165923 | 3117 5 1 4 1 1 53 12 2 9639 2 7 929 |
| 19 | Lecanora carpinea | C | . | | 2 1 211 1 21 11 1 | 1 |
| 53 | Physconia grisea | C | . | | 1 | 1 2 2 2 |
| 8 | Candelariella vitellina | C | . | | 11 1 1 | 2 |
| 31 | Opegrapha atra | C | . | | 1 | 1 |
| 33 | Parmelia acetabulum | C | . | | 1 1 | 1 |
| 49 | Physcia biziana | D | . | 1 | 2 1 1 1 | 3 1 1 1 1 8 |
| 56 | Rinodina sophodes | C | . | 1 | 1 9 1 | |
| 20 | Lecanora conizaeoides | C | . | | 1 3 | 1 2 |
| 2 | Arthrosporum populorum | C | . | | 2 | 3 |
| 45 | Phaeophyscia chloantha | C | . | | 4 1 8 | 5 997277 3 1 11 5 1 2 1 5 8 1 3 |
| 10 | Catillaria nigroclavata | C | . | | | 3 2 1 |
| 58 | Xanthoria fallax | C | . | | | 2 3 |

this feature, also hosts several suboceanic species. Groups 3 and 4 clearly have an higher incidence of *Xanthorion*-species, the latter differing in a lower number of species per station. On the whole, these results are in good agreement with those relative to the analysis of relevés, which means that the vegetational situation within every single station tends to be homogeneous.

The average values of Wirth's ecological indices in the stations were processed by automatic mapping programs to test the use of the indices for mapping some main ecological features of the territory. The geographic distribution of the index of nitrophytism is shown in Fig. 11a: the result is in good agreement with what is known about land use: the most eutrophicated areas are those of the coastal district, with intensive agriculture, the less eutrophicated those of the Collio and Karst districts, with the lowest impact of agricultural activities. The geographic distribution of the index of hygrophytism is shown in Fig. 11b. This map is almost the opposite of the previous one: most xerophytic species occur in areas with high eutrophication, while most hygrophytic species are more frequent in semi-natural areas with low human impact. This is quite understandable considering that most of the plains are reduced to an "agricultural steppe" while the Collio and Karst districts, besides having a more humid climate, host a much more developed woody vegetation influencing the local microclimatic conditions towards still more humid situations.

The data of Tab. 2 were also used to draw

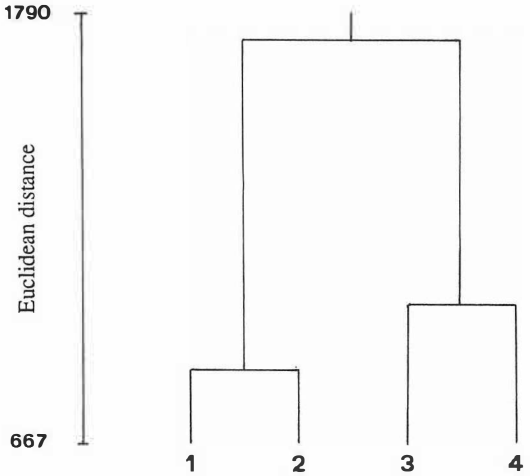


Fig. 10 - Dendrogram of the stations, based on the data of Tab. 3, showing only the four main clusters (minimum variance clustering, euclidean distance).

distribution maps of some of the most common species. A selection is shown in figure 12, reporting, the distribution patterns of *Parmelia caperata*, *P. sulcata*, *P. subrudecta*, *Candelaria concolor*, *Hyperphyscia adglutinata*, *Phaeophyscia orbicularis* and *Xanthoria parietina*. These maps are briefly commented on in the following.

The three species of the genus *Parmelia* s.lat. tend to be most frequent in the northern part of the province, being almost absent in the Coastal Plain. In particular, *Parmelia caperata* has its optimum in relatively elevated areas with semi-natural vegetation (open woodlands) such as the Collio and Karst districts, *Parmelia sulcata* is restricted to the northern part of the province, but isable to penetrate within the urban area of Gorizia, probably because of the relatively humid climate and the acidification of bark caused by air pollution; the capability of this species to re-colonize relatively polluted areas was reported for the town of Udine (Nimis 1986), and for the low Venetian Plain (Nimis *et al.* 1991). *Parmelia subrudecta* has a similar distribution pattern, but is able to expand widely into the Isonzo Plain district, which accords well with its ecology: this species is somehow intermediate between *Xanthorion* and *Parmelion*, being most frequent in somehow eutrophicated *Parmelion* stands, and in relatively less eutrophicated *Xanthorion* vegetation, always in situations of low air pollution. The remaining species clearly belong to the *Xanthorion* element

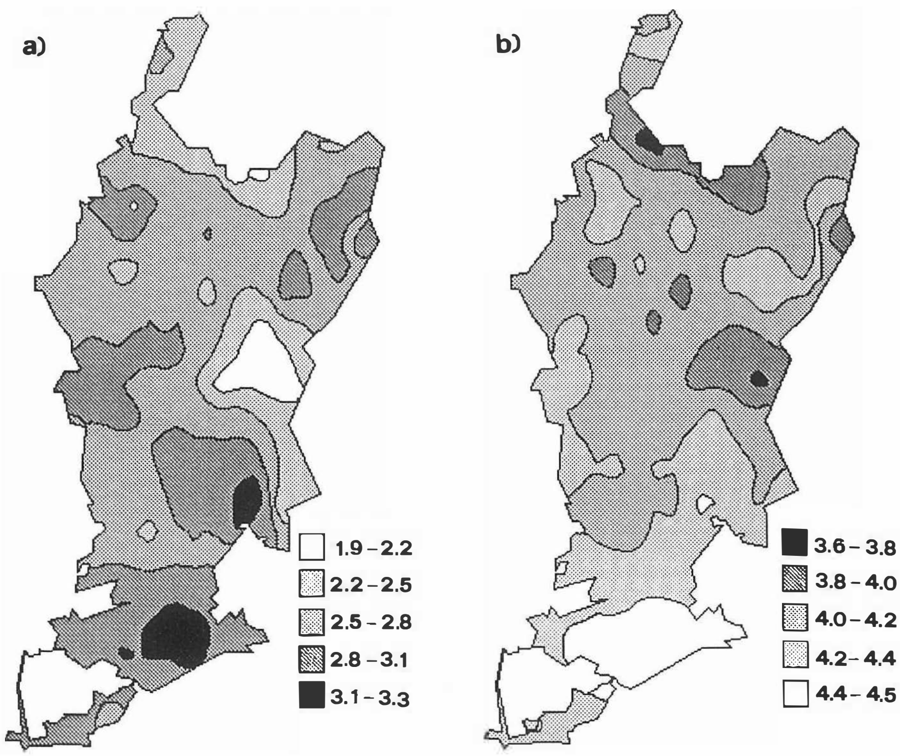


Fig. 11 - Isoporic map showing the distributions of the weighted averages of Wirth's index of nitrophytism (a) and of hygrophytism (b) in the 104 sampling stations.

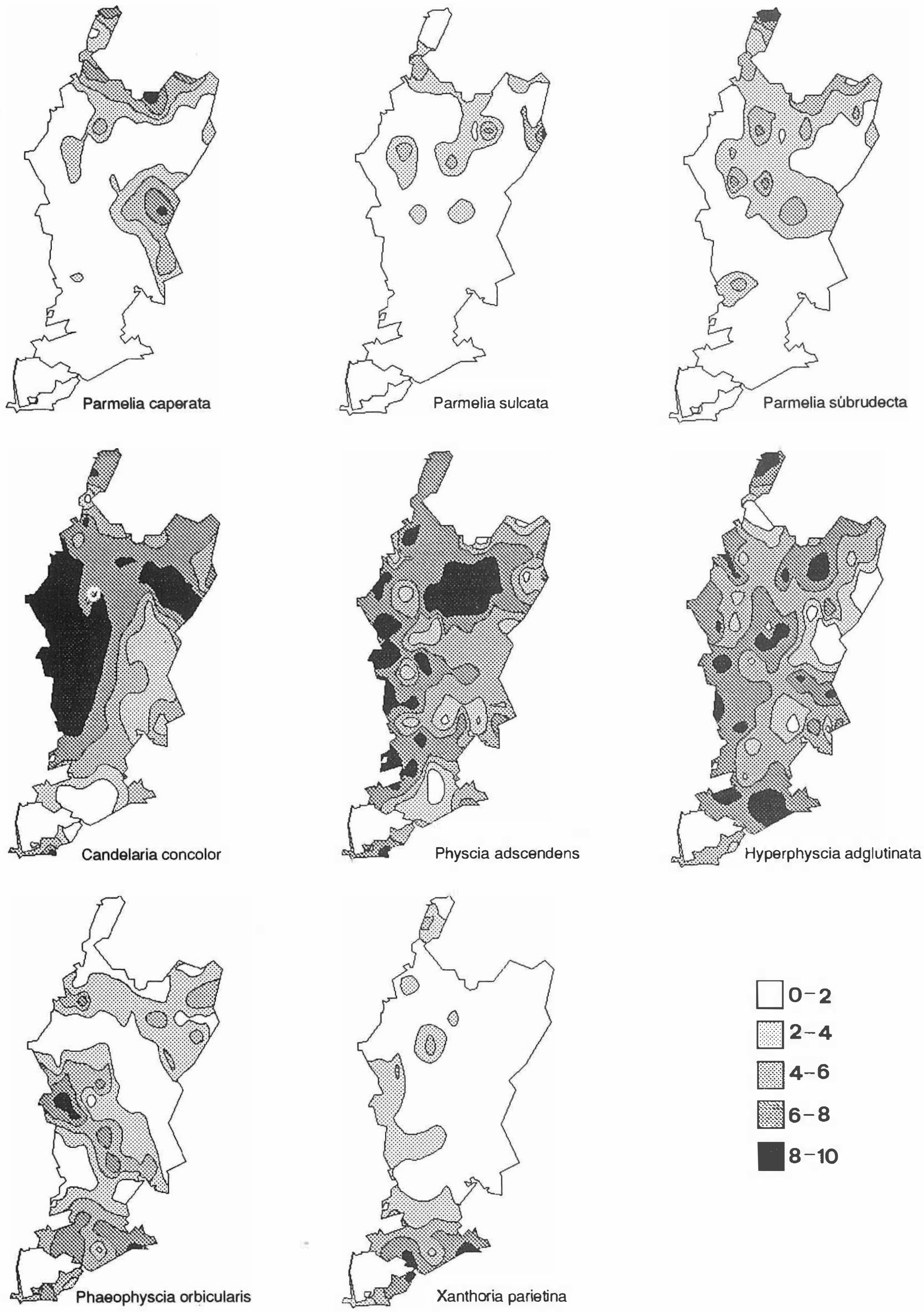


Fig. 12 - Distributions and abundances of eight selected species in the survey area, based on average frequency in the 104 sampling stations.

which is redominant in the survey area: *Candelaria concolor*, *Hyperphyscia adglutinata* and *Physcia adscendens* are the three most common lichens of the province. All of them are typical of eutrophicated situations. This ecological similarity is reflected in a corresponding congruence of distribution pattern: although present throughout the survey area, these species have their optimum outside the Collio and Karst districts, i.e. in the areas which are most heavily exploited by agriculture. The distribution of *Phaeophyscia orbicularis* differs in being mainly western and southern. Finally, *Xanthoria parietina* is clearly most frequent in the Coastal district, perhaps due to the effects of salt spray from the coast towards the interior. Summing up, *Parmelion* and *Xanthorion* species have complementary distributions within the survey area, the former being favoured by more natural conditions, the latter by anthropization, and especially by intensive agriculture (eutrophication).

The map of IAP values relative to the 104 sampling stations is shown in Fig. 13. The survey area has been subdivided into eight belts with different IAP values, using the same intervals adopted by Nimis *et al.* (1991) for the Region of Veneto, and by Castello *et al.* (1995) for the province of Trieste, in order to facilitate the comparison. The highest values were recorded in the Collio district, an area without relevant industries and widespread intensive agriculture; somehow lower values are reached only near the town of Cormons, probably because of urban pollution by domesting heating and local industries (see Figs. 1 b,c). High IAP values also characterize the Isonzo Plain and Karst districts, two areas without relevant concentrations of industries and intensive agriculture. The southern part of the Karst district, however, shows lower IAP values, most probably because of the influence of Monfalcone and its industrial area. This town and its surroundings have the lowest IAP values in the entire province; the negative influence of Monfalcone on IAP values extends towards southwest, in accordance with the direction of the prevailing northeastern winds. Monfalcone is certainly the part of the province with highest air pollution levels, due to three main factors: its relative large population (domestic heating), the presence of a large electric power station, the existence of a large industrial area east of the town. The area surrounding Gorizia also has IAP values lower than 20, although these are limited to a restricted portion of the town. The influence of Gorizia and its industrial area extends some kilometers southwards, up to the village of Savogna.

When compared with situations known from other parts of northeastern Italy, such as the whole Veneto region (Nimis *et al.* 1991) and the province of Trieste (Castello *et al.* 1995), that of the survey area is, as far as IAP values are concerned, relatively good: no extended lichen desert does occur, the areas with IAP values lower than 20 are very limited, and most of the province has a situation comparable to that of the Dolomites (Nimis *et al.* 1991), or of the Trieste Karst (Castello *et al.* 1995), two areas which are notoriously free from heavy pollution phenomena.

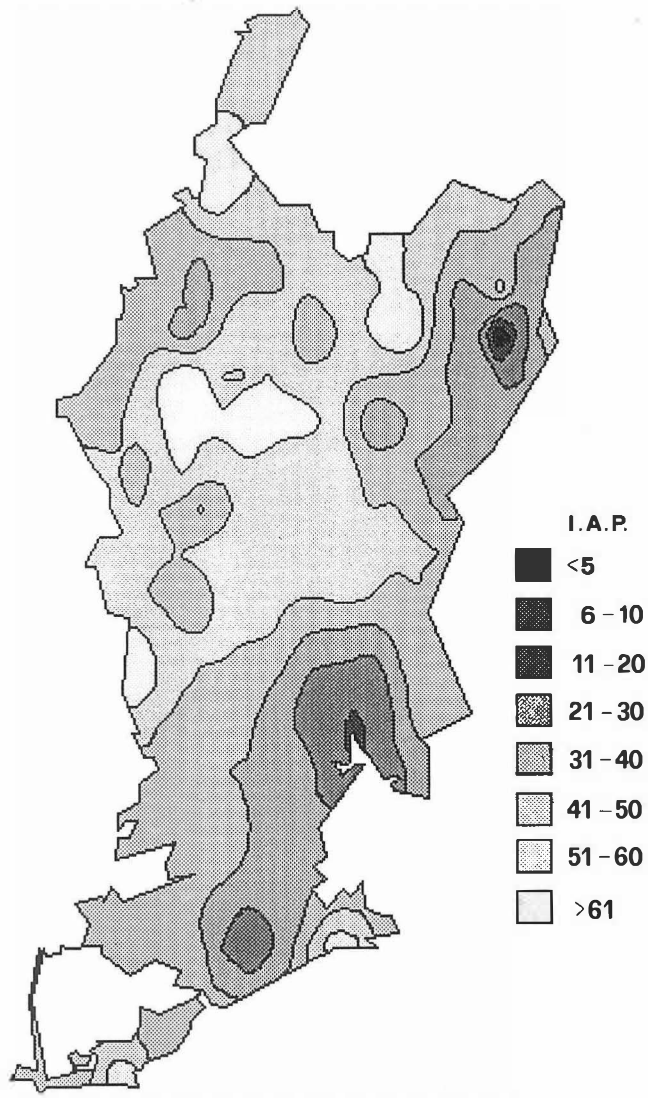


Fig. 13 - Map of the Index of Atmospheric Purity (IAP) in the survey area. The area has been subdivided into 8 belts, as in the legend.

## Conclusion

According to Nimis (1990), one of the main reasons for the scarcity of studies relating air pollution with health risk is the scarce availability of reliable pollution data over vast areas, to be used in epidemiological studies. The high costs of recording instruments is a severe constraint on their spatial density. A high spatial density of recording stations, however, is essential for properly monitoring pollution phenomena, which are so variable in space and time. The use of lichen biodiversity values cannot be considered as a substitute of direct pollution recording, also because current legislation, in defining thresholds for given pollutants, refers to actual concentrations in the atmosphere, and these can be measured only by appropriate instruments. Even with lichens, well-known for being among the best bioindicators of air pollution, the interpretation of IAP values in terms of actual air pollution levels is not easy. Biodiversity values, which in our case are limited to number and frequency of species per sampling unit, may depend on several factors other than air pollution, such as climatic conditions, the vegetational situation of the area, and land use. In our study, the climatic situation of the survey area is sufficiently homogeneous as to exclude an important effect on IAP values: some species are clearly more frequent in certain, climatically different parts of the survey area, but the overall IAP map does not show any correlation with climatic parameters. A correlation with land use and natural vegetation, on the contrary, is evident: higher IAP values are reached in the less urbanized and less industrialized areas, i.e. those which host a more natural vegetation. On the contrary, the lowest values are reached near important urban agglomerations and/or industrial areas. This, however, is a further good evidence for the use of lichen biodiversity measurements as indicators of air pollution.

That lichens are sensitive to several different pollutants is now demonstrated by thousands of publications, and nobody would question this well-known fact. The methodology for IAP measurement adopted in this study proved to have a very high predictive value with respect to the sum of several different pollutants in Switzerland (Herzig & Urech 1991). The same type of measurement showed a good correlation with direct data concerning $SO_2$ concentrations in La Spezia (NW Italy, Nimis *et al.* 1990). Finally, the IAP map of the entire Region of Veneto, obtained through the same method, proved to be extremely well-congruent with a map of death risk by lung cancer (Nimis & Cislaghi, in prep.). Thus, there is unmistakable evidence that lichen biodiversity is strongly related to air quality. The use of these organisms as bioindicators of air pollution has two main advantages: lower costs and, hence, a higher density of sampling stations. In this way the imprecision of the single measurement in terms of air pollution estimate is amply compensated by the high sampling density, which strongly improves the data quality of the maps. The use of lichens as bioindicators can constitute a useful complement to instrumental pollution monitoring in showing the main "high risk areas", and in optimizing the positioning of the few, costly recording instruments on the territory.

In the case of our survey area, compared with the situation prevailing in northeastern Italy, lichens do not suggest the existence of particularly high pollution levels: the only areas which would be worth monitoring in more detail are parts of the Coastal district and the surroundings of the provincial Capital, Gorizia.

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*Received September 4, 1996*
*Accepted September 30, 1996*