

URBAN LICHEN STUDIES IN ITALY Ist: THE TOWN OF TRIESTE

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Abstract. This paper reports on the distribution of lichens in the urban environment of Trieste (NE-Italy) and its surroundings. The study is based on 213 phytosociological relevés, taken on trees with primarily acid bark, and on pollution data from a net of deposimetric stations located within the town center. Both data sets have been submitted to multivariate analysis (classification and ordination). The results of data analysis allowed to distinguish six main zones, three defined by a peculiar lichen vegetation, the remaining three delimited on the basis of pollution data. The ecology of the relevé groups obtained by classification has been studied on the basis of the tolerance ranges associated to each species by Wirth (1980). From the periphery to the center of the town there is a decrease in species, and an increase in the relative frequency of xero- photo- nitro- and neutro-basiphytic species. The distribution of lichens within the survey area cannot be explained on the only basis of air pollution. Drought in the urban environment seems to be another important factor affecting the distribution of lichens in the town of Trieste.

Introduction

Lichens have been often claimed to be good indicators of air pollution (for a review of the abundant literature on this subject see Ferry et al., 1973). Some authors, however, (Beschel, 1958; Rydzak, 1969) thought that drought in urban environments is the main cause of the scarcity of lichens in towns. The latter hypothesis was strongly criticized, above all by authors working in Western Europe (see Coppins, 1973). The number of towns whose lichen floras have been studied in connection with pollution studies is very high. Zone-maps have been drawn for many of them and scales have been worked out by means of which it seems possible to predict pollution levels from features of the lichen flora and vegetation. Nevertheless, such scales are obviously valid only within areas with a given lichen flora and with given climatical conditions. Most of them (see Barkman, 1958; Hawksworth & Rose, 1970) refer to Northwestern Europe, that has an oceanic - suboceanic climate, and their use in Italy is problematic. To my knowledge, up to now only three studies have been published on lichens and air pollution in Italy. The first refers to a mountain valley in the Eastern Alps (Caniglia et al., 1978): 5 species are mentioned and the study is mainly centered on *Xanthoria parietina* and *Physconia pulverulacea*. The second was carried out in a small village in the Western Alps (Pierivittori & Montacchini, 1980), and cites 8 species. The last (Caniglia &

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Drudi, 1984) concerns the lagoon of Venice, where, according to the authors, 31 species are present (on all kinds of substrate).

This paper is the first of a series whose subject is the study of epiphytic lichens in urban environments within the Italian territory. The first three papers of the series treat the towns of Trieste (this paper), Udine (Nimis, 1986) and Rome (Nimis, in prep.). Aim of these papers is simply the analysis of distribution patterns of lichen species in the three towns, in order to provide a basis for further studies on lichens as indicators of air pollution in the Italian territory.

Description of the survey area

The town of Trieste is located in NE Italy, at Lat. 45°40' N, Long. 13°46' E. The elevation goes from sea level to 405 m at the edge of the Karst Plateau. The population is of 257.697 people (data of 1980). The phanerogamic vegetation of the surroundings of Trieste has been the object of several studies (Lausi & Poldini, 1962; Poldini, 1972, 1975, 1980, 1981, 1982). A characteristic of Trieste is the complete absence of extensive cultivations in the surroundings of the town, so that there is a relatively sharp transition between a urban and a semi-natural environment, the latter mainly characterized by rather well developed *Quercus*-woods. The lichen flora of some sites in the surroundings of the town has been studied by Nimis & Loi (1982a and b, 1984) and Nimis & Losi (1983). The epiphytic lichen vegetation has been studied by Nimis & De Faveri (1981) and Nimis (1982).

The climatic diagram of the town is in Fig. 1. The climate is transitional between the mediterranean and the continental climate types, with relatively strong differences between the coastal strip and the inner, more elevated portion of the area. Mean yearly precipitation in Trieste is 952 mm (Fig. 1), whereas on the Karst

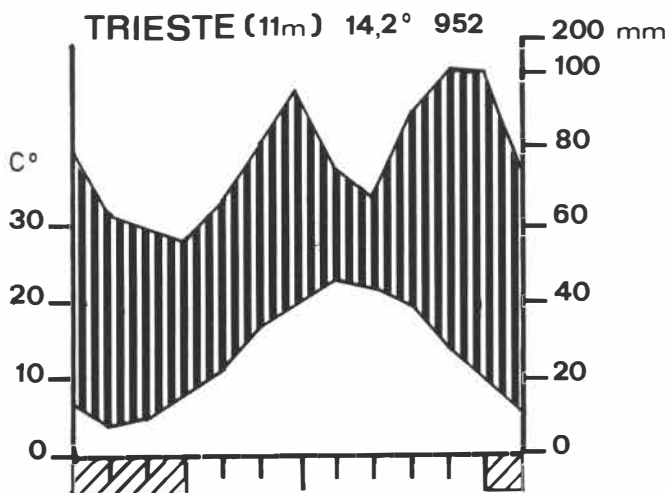


Fig. 1 — Climatic diagram of Trieste.

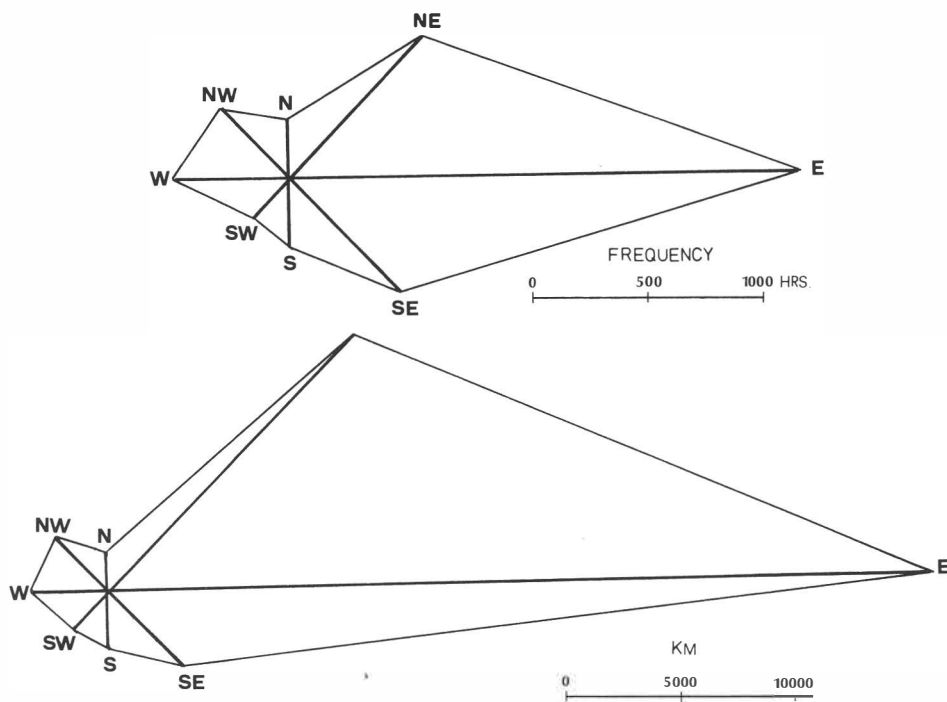


Fig. 2 — Average yearly wind speed and wind frequency in the town of Trieste (redrawn from Polli, 1971).

plateau (Opicina) it is 1157 mm (Polli, 1961). Mean yearly temperature in Trieste is 14.2° C, in Opicina 11.1° C. The climatic diagram of Trieste (Fig. 1) shows a maximum of precipitation in Autumn. The area is frequently subject to strong dry winds blowing from ENE (Bora) (Fig. 2); they are particularly frequent in winter, when the speed may be over 120 Km/h. A warm-humid wind blows from SW (Scirocco), normally bringing rainy weather. The prevailing action of the Bora-wind and the low water-holding capacity of the limestone rocks surrounding the town contribute to relatively low air humidity (average 65%, Poldini 1980) throughout the year.

Data and methods

A reference grid with squares of 500 m has been superimposed to the map of Trieste (see Fig. 3). In some cases (particularly hills where the same subdivision includes areas with different exposure) the adopted squares had a side of 250 m. The squares constitute the reference for drawing maps concerning the distribution of lichens. The survey area (Fig. 3) includes the town itself, plus the edge of the Karst Plateau, with the village of Opicina. The outskirts of the town are occupied by a semi-natural vegetation dominated by oaks (*Quercus pubescens* on limestone,

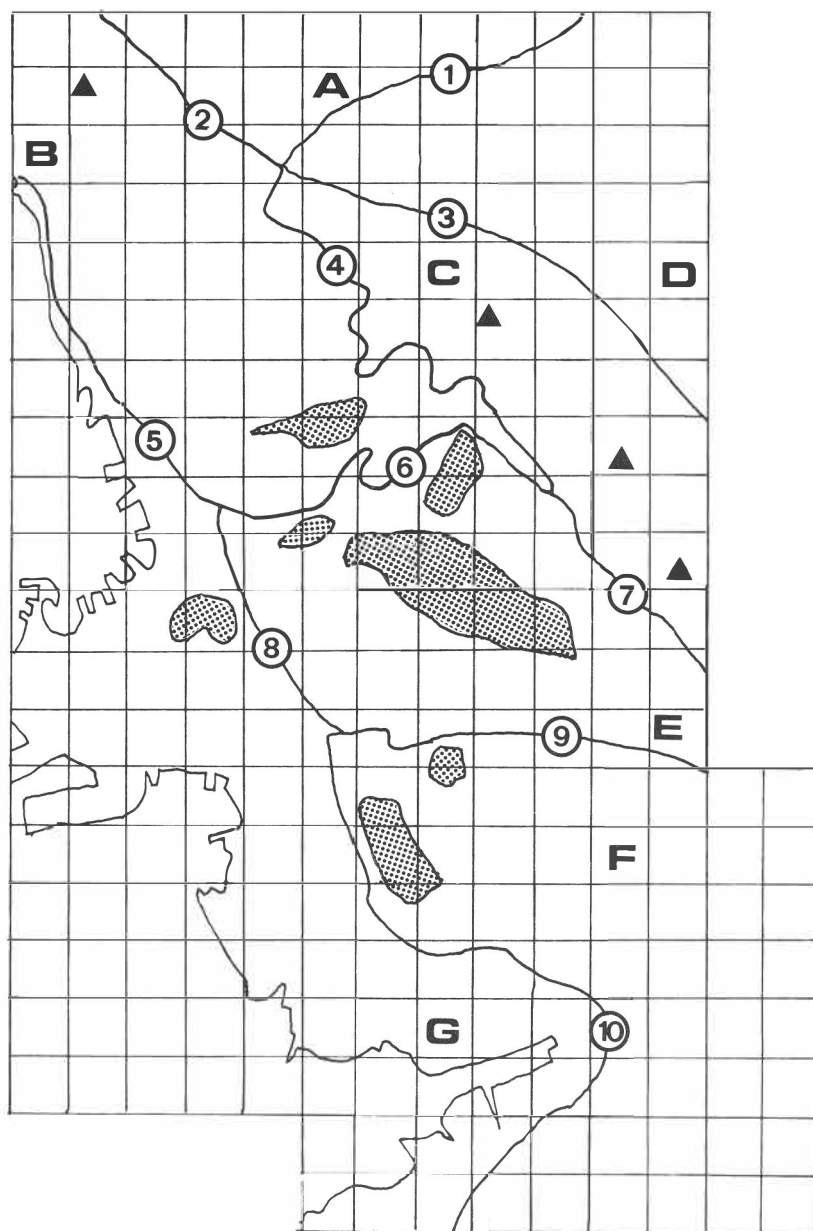


Fig. 3 — Map of Trieste with reference grid. Circled numbers refer to main roads, as follows: 1) Via Nazionale, 2, 3) SS 202, 4) Strada Nuova per Opicina, 5) Viale Miramare, 6) Via F. Severo, 7) Strada per Basovizza, 8) Via Carducci, 9) Autostrada, 10) Via Flavia. Letters refer to main villages in the hinterland: A) Opicina, B) Barcola, C) Banne, D) Trebiciano, E) Melara, F) S. maddalena Inf., G) Industrial area. Dotted areas are the main parks within the urban area proper. The triangles indicate the main peaks along the ridge of the Karst Plateau.

Quercus petraea on sandstone), and several green areas are available within the town for sampling of epiphytic lichens. As porophytes, trees were selected whose bark is primarily acid. These are (in order of frequency): *Quercus*, *Robinia*, *Tilia*, *Aesculus*, *Platanus*. Relevés were taken at the North and South sides of the boles, at the base and at 1.5 m up on the bole, within squares of 50 cm. Each subdivision of the town is represented by 1 to 5 porophytes. A relevé consists in a complete species list, with cover values according to the cover/abundance scale of Braun-Blanquet (1964). Severe damage (decortication) of species was also recorded when evident in more than 20% of the specimens present in the plot. Sampling was carried out in 1981 and in the first half of 1982.

Pollution data were kindly supplied by the Laboratorio di Igiene e Profilassi della Provincia di Trieste (Dr. Severi). They are averages of 5 years long measurements in a net of 28 deposimetric stations, mostly located within the urban area of Trieste. They concern: insoluble substances, soluble substances, ashes of soluble and insoluble substances (the difference gives the amount of organic material), ions Cl, SO, Ca, Mg: these measures are obtained by analysis of the soluble substances, and are related to pollution by industries and traffic (chloridric acid, sulphur dioxide, dust). No direct measurements of the concentration of sulphur dioxide within Trieste were available.

Both floristic and pollution data have been submitted to multivariate analysis (classification and ordination), as follows:

- a) Classification, in order to detect groups of similar cases (relevés, deposimetric stations), or variables (species). Complete Linkage Clustering (Anderberg, 1973) was used, with correlation coefficient as similarity measure in the case of floristic data (presence-absence values), and similarity ratio (see Westhoff & Van der Maarel, 1973), after data standardization, in the case of pollution data (quantitative data).
- b) Concentration Analysis (AOC, Feoli & Orloci, 1979), on the contingency table of species and relevé groups, in order to quantify their respective correlations.
- c) Ordination, both for relevés and deposimetric stations, in order to test the existence of compositional or pollution trends. Principal Component Analysis has been used (see Orloci, 1978), with similarity ratio on quantitative data, after standardization (both for relevés and stations).

A further data source, utilized for the ecological interpretation of relevé groups, are the tolerance ranges assigned to each species by Wirth (1980). They concern: pH, light, moisture and nitrates. Furthermore, direct data on the pH of the bark were obtained for 138 trees: 2 g of pulverized bark have been left in 16 ml of distilled water for 24 h, and the pH was measured with a digital pH-meter.

The distribution of the relevé groups and of the groups of deposimetric station obtained by classification has been reported on maps, and the results of data analysis have been used to discuss the main factors affecting the distribution of lichens in the urban environment of Trieste. A zone-map has been constructed, chiefly based on the distribution of relevé and station groups, with minor modifications derived by subsequent observation of lichen vegetation within

subdivisions of the town that were particularly "critical" (top of hills, border zones between two areas in which a given vegetation type is prevalent etc.)

Results

Analysis of pH and floristic data

The pH of the bark of the 5 porophytes selected for sampling is as follows: *Quercus pubescens* + *Q. petraea* (53 measures) 4.7 at 1.5 m, 5.0 at tree base; *Robinia pseudacacia* (25 measures): 5.3 at 1.5 m, 7.0 at tree base; *Tilia cordata* (20 measures): 5.5 at 1.5 m, 7.0 at tree base; *Aesculus hippocastanus* (20 measures): 5.6 at 1.5 m, 6.8 at tree base. *Platanus orientalis* (20 measures): 6.1 at 1.5 m, 6.9 at tree base. The pH at tree base is around 7.0 for all of the species except *Quercus*. The reason is that at tree base accumulation of dust and nitrates is higher, above all on trees located along roads. *Quercus* is never planted as a wayside tree in the study area, and most of the relevés on this porophyte have been taken in natural or semi-natural vegetation outside of the most heavily urbanized areas, where accumulation of nitrates at the base of the boles is lower.

The results of the classification of relevés and species are shown in Fig. 4. Five

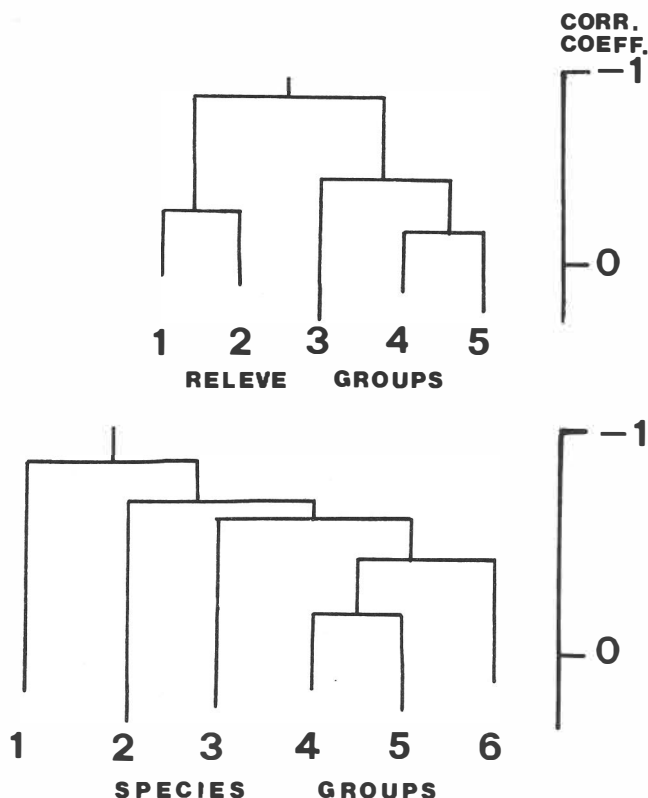


Fig. 4 — Dendrograms of relevé and species groups.

main releve groups and six main species groups are formed. The relative frequencies of the species in the releve groups are in Tab. 1. The degrees of

S.P.G.R. No.	SPECIES	RELEVE GROUPS				
		1	2	3	4	5
1 1	Evernia prunastri	* 100.0 (+)	10.5 (+)			
1 2	Hypogymnia physodes	* 91.6 (1)	5.2 (+) _o			
1 3	Usnea hirta	* 41.6 (+)	5.2 (+) _o			
1 4	Parmelia subaurifera	* 66.6 (2)	31.6 (1)		23.1 (+)	
1 5	Parmelia caperata	* 100.0 (3)	63.1 (2)	10.0 (1)	15.4 (1)	13.6 (+) _o
1 6	Parmelia sulcata	* 100.0 (3)	47.3 (3)	20.0 (1)	46.1 (1)	9.1 (+) _o
1 7	Parmelia tiliacea	* 66.6 (2)	36.8 (2)	20.0 (1)	7.7 (+)	4.5 (+) _o
1 8	Parmelia subrudecta	* 83.3 (1)	73.6 (1)	60.0 (1)	15.4 (1)	11.3 (+) _o
2 9	Parmelia glabra	*		100.0 (4)		
2 10	Parmelia quercina	*		100.0 (1)		
2 11	Parmelia acetabulum	*		80.0 (3)		
2 12	Parmelia exasperata	* 16.6 (+)	5.2 (+)	60.0 (+)	6.3 (+)	
3 13	Normandina pulchella	* 8.3 (+)	5.2 (+)	10.0 (+)		
3 14	Caloplaca ferruginea	*	10.5 (1)	10.0 (+)		
3 15	Cladonia fimbriata	* 8.3 (+)				2.3 (+) _o
3 16	Cladonia coniocraea	* 8.3 (+)				2.3 (+) _o
3 17	Lecanora symmictera	* 8.3 (+)				
3 18	Buellia punctata	* 8.3 (+)	5.2 (+)			4.5 (+)
3 19	Ramalina fastigiata	* 8.3 (+)			7.7 (+) _o	
3 20	Scoliosporum chlorococcum	* 16.6 (+)				4.5 (+)
4 21	Physciopsis adglutinata	*			7.7 (+)	
4 22	Candelariella reflexa	* 75.0 (1)	21.0 (+)		76.9 (1)	22.0 (+)
4 23	Lecidella elaeochroma	* 50.0 (1)	42.1 (1)		76.9 (2)	22.7 (1)
4 24	Physcia biziana	* 33.3 (+)	31.6 (+)		92.3 (2)	56.8 (+) _o
4 25	Parmelia exasperatula	*	7.7 (+)		15.4 (+)	
4 26	Lecanora hageni	*			7.7 (+)	2.3 (+)
5 27	Lecanora chlorotera	* 16.6 (+)	15.7 (+)	40.0 (1)	76.9 (2)	6.8 (+)
5 28	Xanthoria parietina	* 8.3 (+) _o	36.8 (+)	60.0 (1)	84.6 (1)	56.8 (+) _o
5 29	Physconia pulverulacea	*	47.3 (1)	60.0 (2)	84.6 (2)	56.8 (+) _o
5 30	Physconia grisea	*	36.8 (+)		23.1 (1)	4.5 (+)
5 31	Candelaria concolor	* 25.0 (+)	21.0 (+)	20.0 (1)	76.9 (1)	34.1 (1)
6 32	Candelariella xanthostigma	*		10.0 (+)	23.1 (+)	6.8 (+)
6 33	Physcia aipolia	* 8.3 (+)			15.4 (1)	15.9 (+) _o
6 34	Rinodina exigua	*			15.4 (+)	2.3 (+)
6 35	Lecanora carpinea	*	5.2 (+)		15.4 (1)	2.3 (+)
6 36	Caloplaca viperae	*	7.7 (+)		7.7 (1)	
6 37	Caloplaca cerina	*			7.7 (1)	4.5 (+)
6 38	Caloplaca holocarpa	*	5.2 (+)		15.4 (1)	9.1 (+)
6 39	Caloplaca flavorubescens	*			7.7 (+)	4.5 (+)
6 40	Xanthoria fallax	*			7.7 (+)	4.5 (+) _o
6 41	Physcia orbicularis	* 16.6 (+)	21.0 (+)		23.1 (1)	54.5 (1)
6 42	Physcia adscendens	* 38.3 (+)	40.9 (+)	20.0 (+)	59.2 (2)	88.6 (1)
6 43	Lecanora atra	*				2.3 (+)

Sporadic species: Gr.1: Parmelia perlata, Lecidella euphorea, Collema subnigrescens, Physcia pusilloides, Arthonia radiata, Opegrapha atra, Lecanora pallida.
 Gr.2: Collema subfurvum, Collema ligerinum, Pertusaria albescent, Physcia luganensis, Physcia hirsuta, Lepraria incana.
 Gr.3: Bacidia rubella, Anaptychia ciliaris.
 Gr.4: Physcia tenella, Lecania cyrtella, Catillaria nigroclavata, Parmelia glabrata, Arthopyrenia punctiformis, Physcia nigricans.
 Gr.5: Lecanora conizaeoides.

Tab. 1 — Frequency and average cover (in brackets) of the species in the five releve groups obtained by numerical classification of the 213 phytosociological releves.

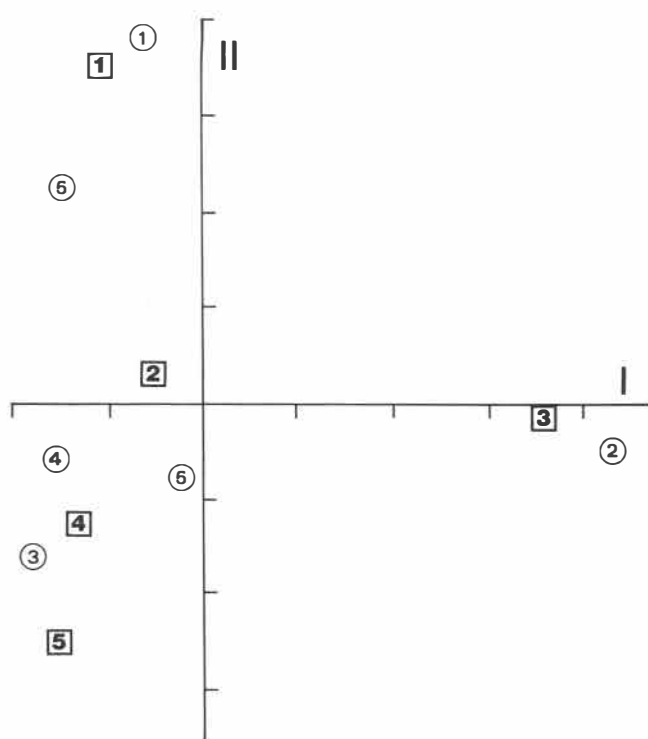


Fig. 5 — Arrangement of releve group and species group - points according to the first two canonical variates of AOC, performed on the contingency table of species and releve groups, as obtained by numerical classification of the matrix of species and releves. Numbers within circles refer to species groups, numbers within squares to releve groups, as in Tab. 1.

correlation between releve and species groups have been quantified by AOC, performed on the contingency table of species groups and releve groups. The results are shown in Fig. 5. The first canonical variate (Fig. 5) clearly separates releve group 3 and species group 2 from the others. Along the second canonical variate the remaining releve groups are arranged in the following sequence: 1, 2, 4, 5, and the species groups in the following sequence: 1, 3, 4, 5, 6. Releve group 1 is clearly correlated with species group 1, releve groups 4 and 5 with species groups 6, 4 and 5, releve group 2 is in an intermediate position between releve groups 1 and 4, 5. The five releve groups may be briefly characterized as follows:

Gr. 1: Mainly characterized by species of group 1. Most of them have their optimum in unions of the order *Parmelietales physodo tubulosae*. Total number of species: 32; mean species number: 11.04, average cover: 80%. Mainly within woods, on *Quercus* at all exposures, mostly at 1.5 m (the base of the boles of *Quercus* within woods is mostly covered by mosses; see Gerdol, 1982), rarely on isolated trees and then always at the N-side of the bole. Constant species are *Evernia prunastri*, *Parmelia caperata* and

Parmelia sulcata; high frequency species are *Hypogymnia physodes* and *Parmelia subrudecta*. The floristic composition of this releve group corresponds well to the one of the *Parmelia* spp. vv. sociation, that, according to Nimis (1982) is the most frequent epiphytic lichen synusia in the *Quercus*- woods of the Karst Plateau near Trieste, outside deep dolines.

- Gr. 2: This releve group is not characterized by any species or species group. Although it is floristically similar to releve group 1 (Fig. 4), it contains also many species occurring in releve groups 4 and 5. No species is present in all of the releves. High frequency species are: *Parmelia subrudecta*, *Parmelia caperata*, *Physconia pulverulacea* and *Parmelia sulcata*. The total number of species is 32, mean species number is 6.4, and average cover is 60%. Mostly at 1.5 m, on isolated trees (*Quercus*, *Robinia*, *Tilia*) North-exposed. For the absence of any differential species, this group cannot be assigned to any clearly defined vegetation type, and is transitional between the *Parmelietales* and *Physcietales* Orders.
- Gr. 3: This group, including only 10 releves, is very well defined by the very high correlation with species group 2, including, in order of frequency: *Parmelia glabra*, *Parmelina quercina*, *Parmelia acetabulum*, *Parmelia exasperata*. Other frequent species are *Parmelia subrudecta*, *Xanthoria parietina* and *Physconia pulverulacea*. Floristically, this releve group can be easily assigned to the *Parmelietales acetabulae*, that according to Nimis (1982) in the Trieste Karst mainly occurs on isolated trees in wind swept areas. Total number of species: 18, average species number: 6.8, mean cover: 90%. Mainly North-exposed, on isolated trees (*Tilia* and *Quercus*) at 1.5 m.
- Gr. 4: This releve group is mainly correlated with species groups 5 and 6. The most frequent species are: *Physcia biziana*, *Xanthoria parietina*, *Physconia pulverulacea*, *Lecidella elaeochroma*, *Candelariella reflexa*, *Lecanora chlorotera* and *Candelaria concolor*. Total number of species: 35, mean species number: 10.6, mean cover: 60%. Always on isolated trees (all of the 5 porophytes), both at tree base and at 1.5 m, mostly South-exposed (just 2 releves at tree base, North-exposed). Floristically, this releve group corresponds with the *Physcietum adscendentis physciosum bizianae* (Nimis & De Faveri, 1981; see also Nimis 1982), a variant of the *Physcietum adscendentis* that in NE-Italy is restricted to the coastal strip in the Province of Trieste.
- Gr. 5: This releve group has no differential species in respect with the previous one. The main differences are that releve group 5 has a much lower mean species number (4.9), and fewer high frequency species. These are: *Physcia adscendens*, *Xanthoria parietina*, *Physconia pulverulacea*, *Physcia biziana* and *Physcia orbicularis*. The average cover is less than 10%, and many species had poorly developed thalli with frequent damages to the upper cortex (see Tab. 1). The group is here considered as an impoverished facies of the community typically represented by releve group

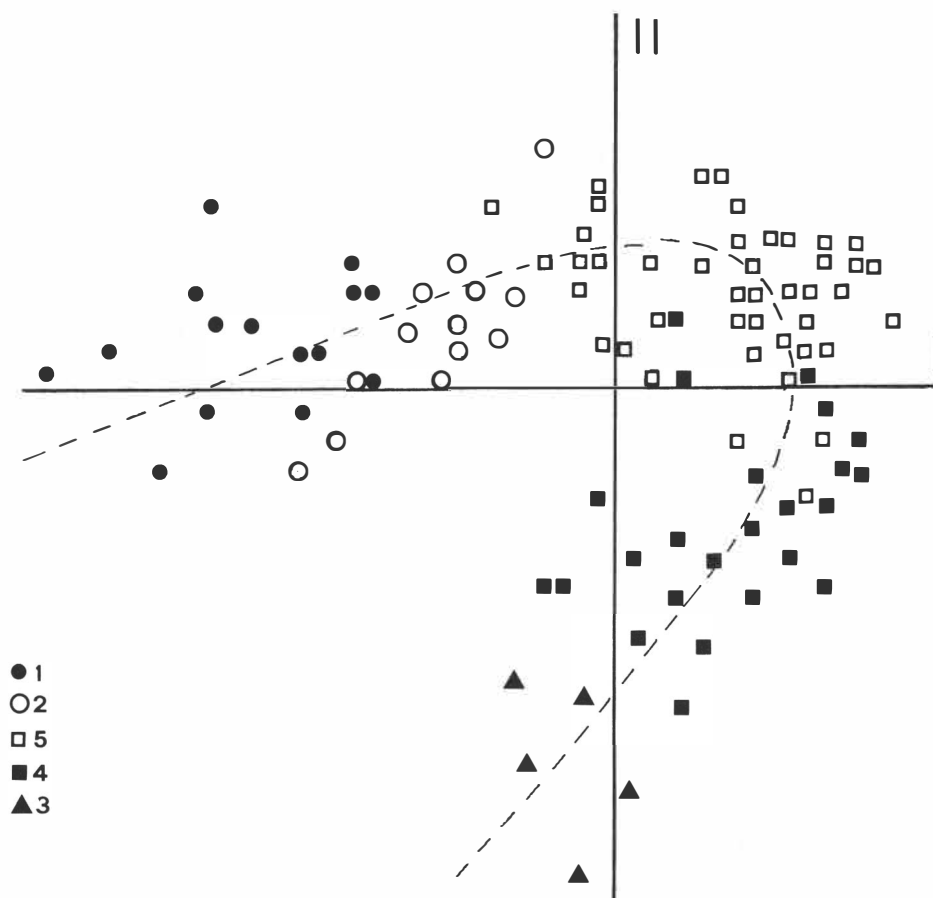


Fig. 6 — Ordination of relevés. Arrangement of relevé points according to the first two principal components. Symbols refer to relevé groups, numbered as in the dendrogram of Fig. 4 (see also Tab. 1).

4. Always at tree base, most frequently (72%) North-exposed, on *Robinia*, *Tilia*, *Platanus* and *Aesculus*, never on *Quercus*.

The results of the ordination of relevés are shown in Fig. 6. The relevés are arranged in the form of a horse-shoe. The sequence of the centroids of the relevé groups along the horse-shoe is: 1, 2, 5, 4, 3. An ecological interpretation of the ordination's results has been attempted on the basis of the indicator values (tolerance ranges) assigned to the various species by Wirth (1980). The relative frequencies in the classes of pH, photophytism, nitrophytism and hygrophytism, calculated over the total occurrences in each relevé group, are in Tab. 2. The results are further visualized in Fig. 7 (a-d), that reports the frequency distributions of the classes of ecological factors in each relevé group, the relevé groups being ordered

CLASSES OF ECOLOGICAL INDEXES (WIRTH, 1980)		RELEVÉ GROUP NUMBERS			
		1	2	3	4
a)					
pH	3.3	1.8	.....	.....	.....
pH	3.4-4.0	51.4	7.7	3.0	1.8
pH	4.1-4.8	85.3	56.1	26.0	20.7
pH	4.9-5.6	75.2	59.1	57.0	41.9
pH	5.7-7.0	31.2	82.3	93.0	87.0
pH	around 7.0	11.0	28.4	37.0	51.6
pH	7.1-8.5	6.4	9.2	12.0	23.0
b)					
skiophytic	A	0.9	.....	.....	.....
rather skiophytic	B	20.1	5.3	3.0	0.9
little skiophytic	C	49.5	23.8	4.0	4.6
rather photophytic	D	77.2	93.8	88.1	95.8
photophytic	E	22.0	33.8	32.6	48.3
c)					
non nitrophytic	A	64.2	43.0	23.1	16.5
little nitrophytic	B	95.4	88.4	75.2	61.7
rather nitrophytic	C	51.3	67.0	84.1	80.6
very nitrophytic	D	12.8	22.3	23.7	42.6
extremely nitrophytic	E	.....	.....	.....	1.4
d)					
extremely hygrophytic	A	4.6	0.7	.....	.....
very hygrophytic	B	41.2	7.7	2.9	.....
rather hygrophytic	C	68.8	25.3	15.8	5.9
mesophytic	D	87.1	66.9	66.3	40.5
rather xerophytic	E	35.7	86.9	86.1	94.4
very xerophytic	F	.....	23.8	31.6	58.8

Tab. 2 — Frequency distribution of occupancies in the classes of ecological indexes, in relevé groups 1-4 (see text).

according to their sequence along the horse-shoe in the ordination scatter diagram (Fig. 6). Relevé group 3 has not been taken into consideration in Fig. 7, since it contains only ten relevés, all taken in a very narrow area with particular ecological conditions (see later). The results may be briefly summarized as follows: the arrangement of the relevés in the scatter diagram of Fig. 6 reflects the following

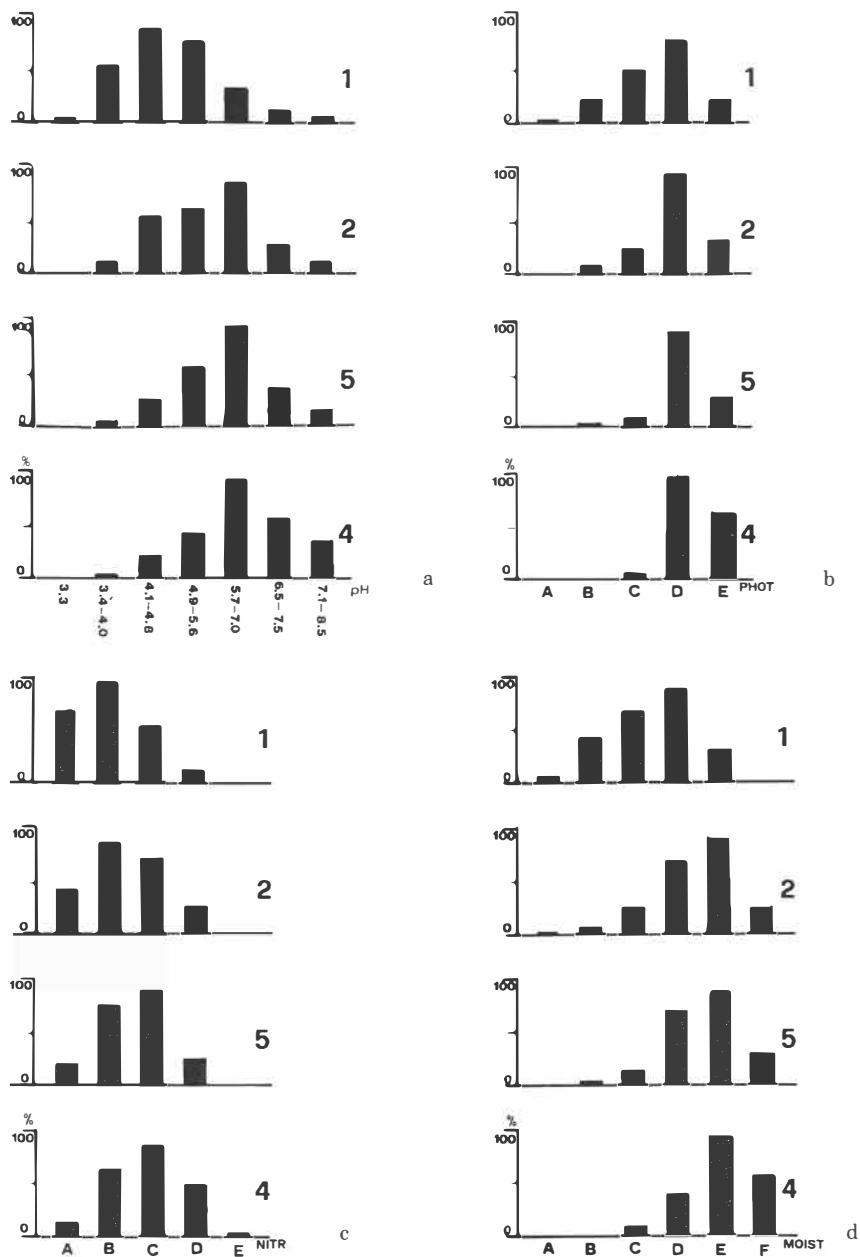


Fig. 7 — Frequency distributions of the classes of ecological factors (as in Wirth, 1980), in releve groups 1, 2, 4, 5. Numbers refer to releve groups, as in Tab. 1, capital letters to classes of ecological factors, as in Tab. 2. a) pH classes, b) photophytism classes, c) nitrophytism classes, d) hygrophytism classes.

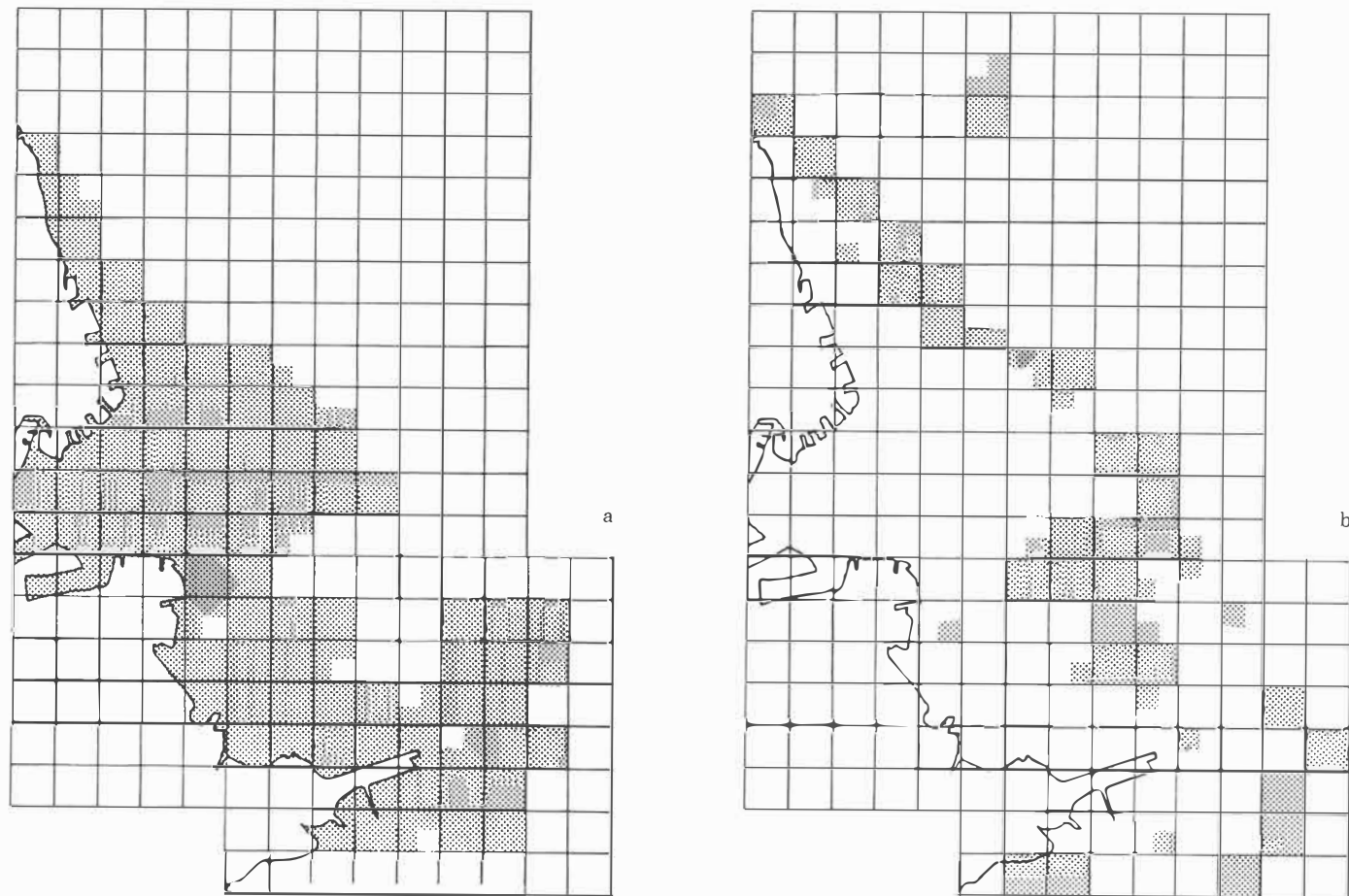


Fig. 8 — Distribution of the releve groups in the survey area. a) lichen desert, b) releves of group 5.

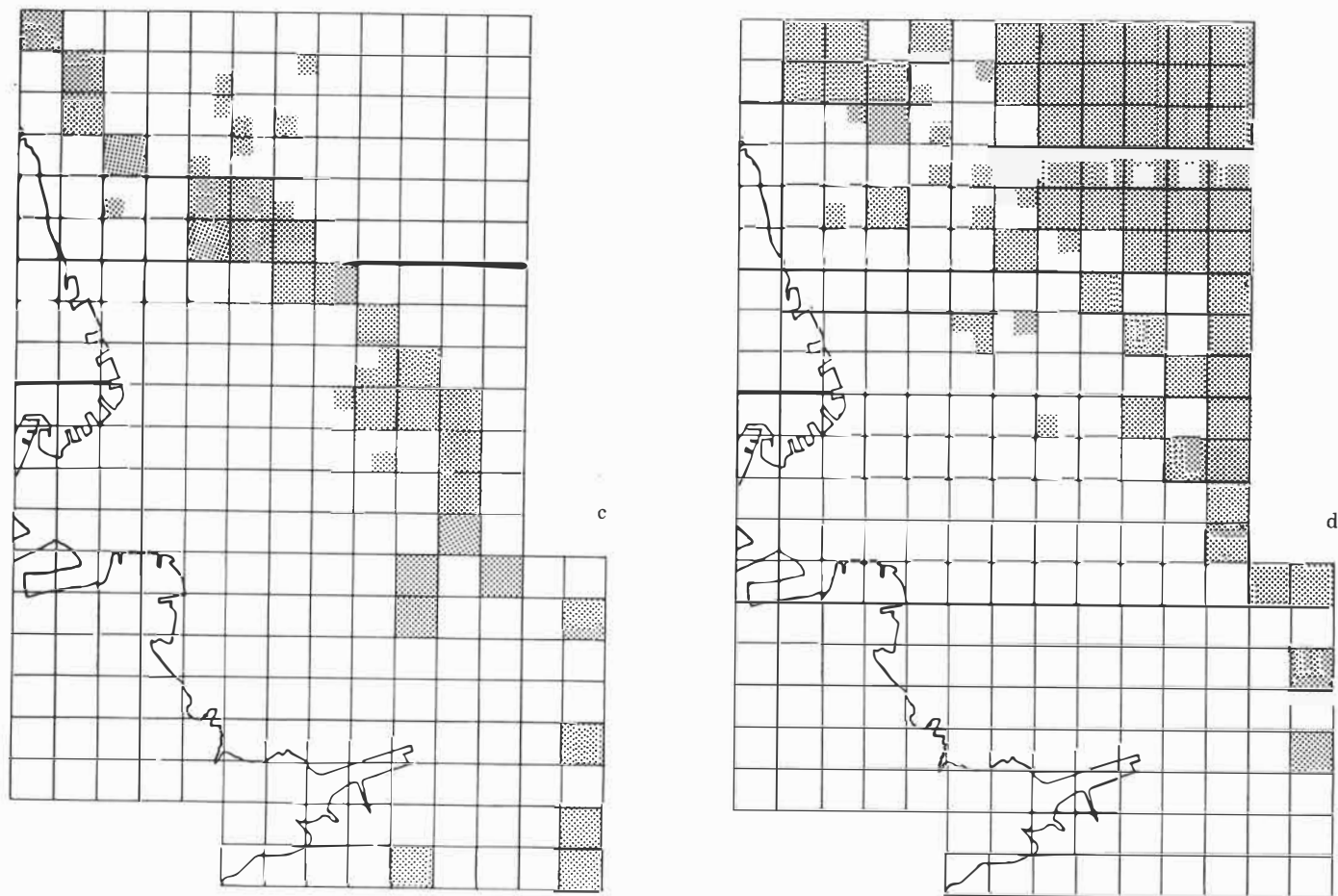


Fig. 8 — Distribution of the releve groups in the survey area. c) releves of group 4; d) releves of groups 1 and 2.

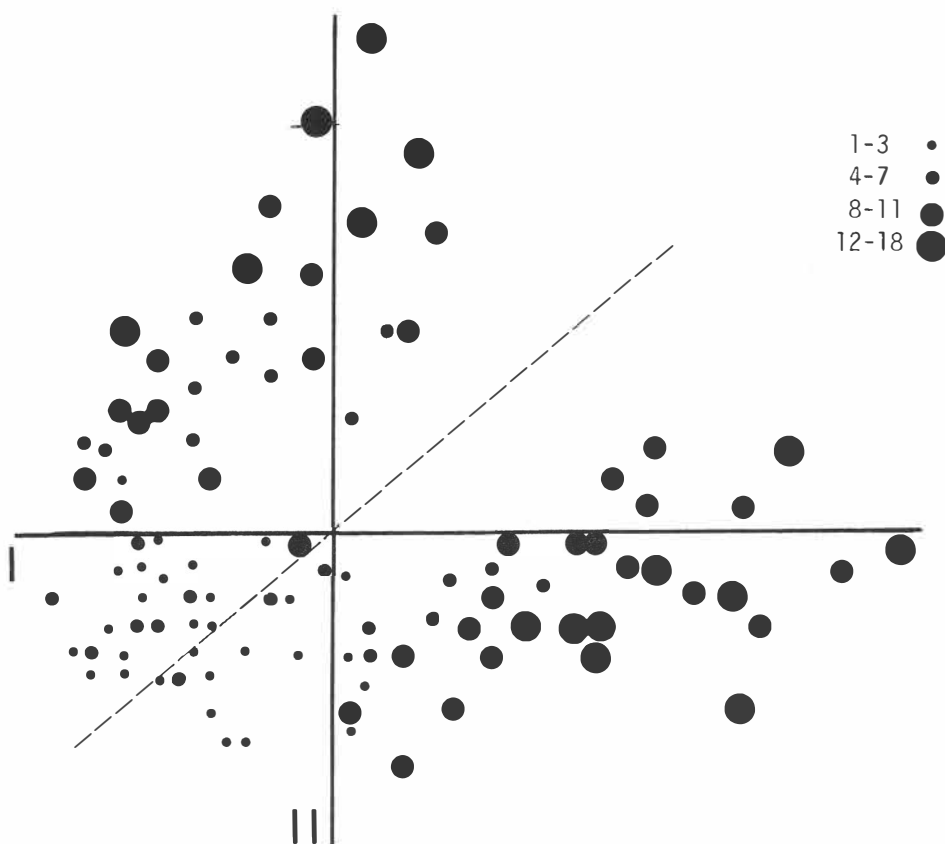


Fig. 9 — Relation between species diversity in the relevés and their arrangement in the ordination of Fig. 6. Size of dots refers to diversity classes, as in the legend.

trends (from releve group 1 to releve group 4):

- increase of neutro-basiphytic species
- increase of photophytic species
- increase of nitrophytic species
- increase of xerophytic species.

Fig. 8 (a-d) shows the distribution of the releve groups in the survey area. The relevés of groups 1 and 2 have been mapped together (Fig. 8d), since they have a very similar distribution pattern, those of releve group 3 have not been mapped, since they are all restricted to the top of the hill of S. Luigi, a rather peculiar, narrow area, very much exposed to the bora-wind. Fig. 8a shows the parts of the town where the trees are completely devoid of lichens ("lichen desert"). From Fig. 8 it is evident that the relevés of groups 5, 4, 1 and 2 have different degrees of poleophoby: less poleophobic are the relevés of group 5, followed by those of group 4, and finally by those of groups 1 and 2. Fig. 9 shows species diversity in the relevés, arranged as in

the ordination scatter diagram of Fig. 6. By rotating the first Principal Component of 45° the relevés are arranged on the new axis according to a gradient of increasing poleophoby. This gradient is paralleled by a increase of the mean number of species in the relevés, from the heavily urbanized areas to the outskirts of the town.

Analysis of pollution data

Tab. 3 reports the pollution data of the 28 deposimetric stations. The location of

ST. No.	A	B	C	D	E	F	G	H
1	1.21	0.60	0.13	0.23	0.12	0.06	0.06	0.24
2	1.16	0.25	0.09	0.17	0.08	0.04	0.07	0.19
3	1.25	0.94	0.13	0.24	0.10	0.05	0.05	0.17
4	0.94	0.54	0.09	0.19	0.08	0.04	0.03	0.15
5	1.26	0.40	0.24	0.48	0.18	0.11	0.09	0.33
6	1.78	1.75	0.11	0.26	0.13	0.06	0.05	0.19
7	0.94	0.27	0.13	0.19	0.11	0.06	0.06	0.24
8	1.01	0.40	0.15	0.18	0.10	0.05	0.15	0.30
9	1.14	0.54	0.13	0.19	0.11	0.05	0.05	0.19
10	1.05	0.80	0.11	0.22	0.10	0.05	0.04	0.17
11	1.22	0.73	0.23	0.29	0.15	0.09	0.21	0.42
12	1.28	0.73	0.25	0.33	0.16	0.10	0.17	0.40
13	1.19	0.75	0.24	0.30	0.16	0.10	0.11	0.30
14	1.53	0.97	0.38	0.42	0.23	0.16	0.48	0.87
15	1.11	0.77	0.20	0.26	0.14	0.08	0.08	0.27
16	2.70	0.94	0.58	0.81	0.48	0.36	1.08	1.76
17	1.15	0.52	0.23	0.23	0.13	0.08	0.11	0.25
18	1.13	0.39	0.18	0.21	0.13	0.08	0.07	0.26
19	1.92	0.56	0.45	0.41	0.27	0.19	0.35	0.61
20	1.39	0.73	0.19	0.26	0.14	0.08	0.08	0.26
21	1.25	1.20	0.15	0.26	0.11	0.06	0.10	0.26
22	0.88	0.77	0.12	0.19	0.13	0.05	0.05	0.22
23	1.32	0.83	0.20	0.22	0.16	0.09	0.09	0.31
24	1.80	1.02	0.46	0.52	0.30	0.21	0.30	0.76
25	1.12	0.42	0.19	0.19	0.12	0.06	0.05	0.22
26	1.14	0.65	0.15	0.24	0.12	0.06	0.06	0.22
27	1.68	1.46	0.14	0.22	0.16	0.07	0.05	0.22
28	1.11	1.02	0.11	0.21	0.10	0.05	0.03	0.16
	$(\text{g/m}^2)^{-3}$	$(\text{g/m}^2)^{-2}$	$(\text{g/m}^2)^{-1}$	$(\text{g/m}^2)^{-1}$	g/m^2	g/m^2	g/m^2	g/m^2

Tab. 3 — Results of the analyses of the 28 deposimetric stations (averages of 5 years). A) Magnesium, B) Chlorures, C) Calcium, D) Sulphates, E) Soluble substances, F) Ashes of soluble substances, G) Ashes of insoluble substances, H) Total fallout.

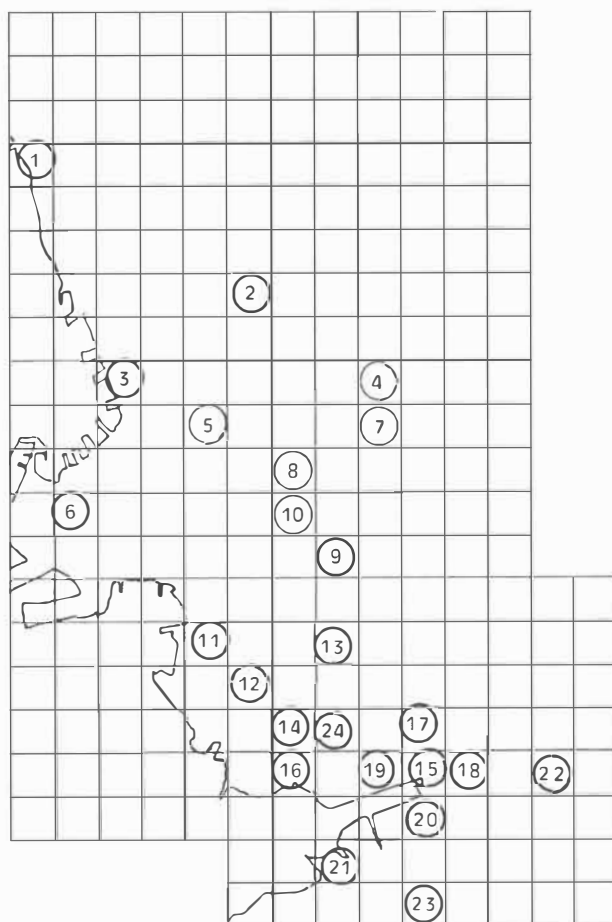


Fig. 10 — Location of the deposimetric stations within the survey area. Numbers refer to the stations, as in Tab. 3.

these stations in the survey area is shown in Fig. 10. 4 stations are outside of the map. The data of Tab. 3 have been submitted to classification and ordination. The dendrogram of the stations is shown in Fig. 11: four main groups (a-d) are formed. The ordination's results are shown in Fig. 12. The first Principal Component accounts for 75.3% of the total variance, the second for 11.9%. The four groups of stations obtained by classification are still recognizable in the ordination; the sequence of their centroids along the first Principal Component is as follows: b, c, d, a. Fig. 13 (a-g) reports the values of the variables in each stations, and the stations are arranged on the x-axis according to their projections on the first Principal Component of Fig. 12. It is evident that the first Principal Component reveals a gradient of decreasing pollution from the left side (station group b) to the right side

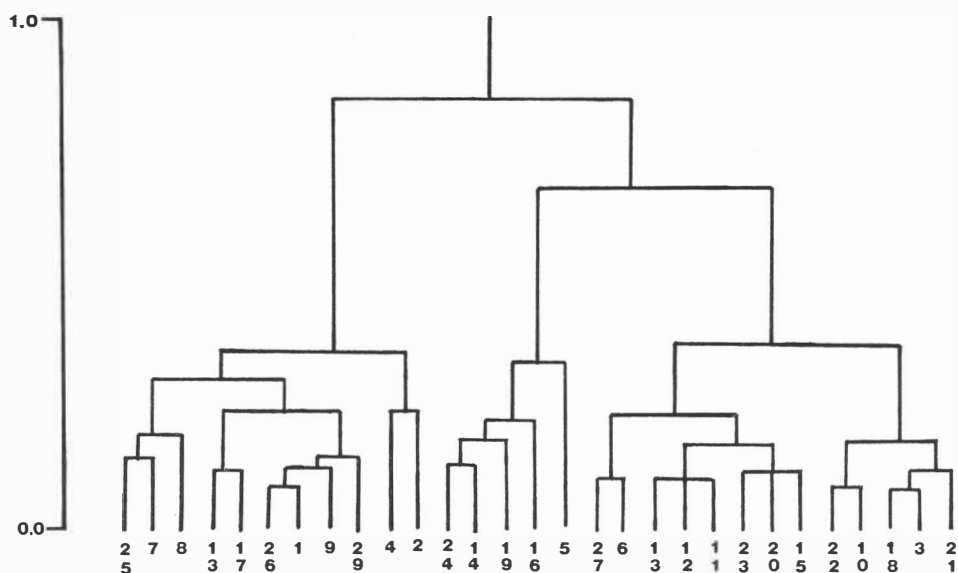


Fig. 11 — Classification of deposimetric stations on the basis of the data in Tab. 3. The stations are numbered as in Tab. 3.

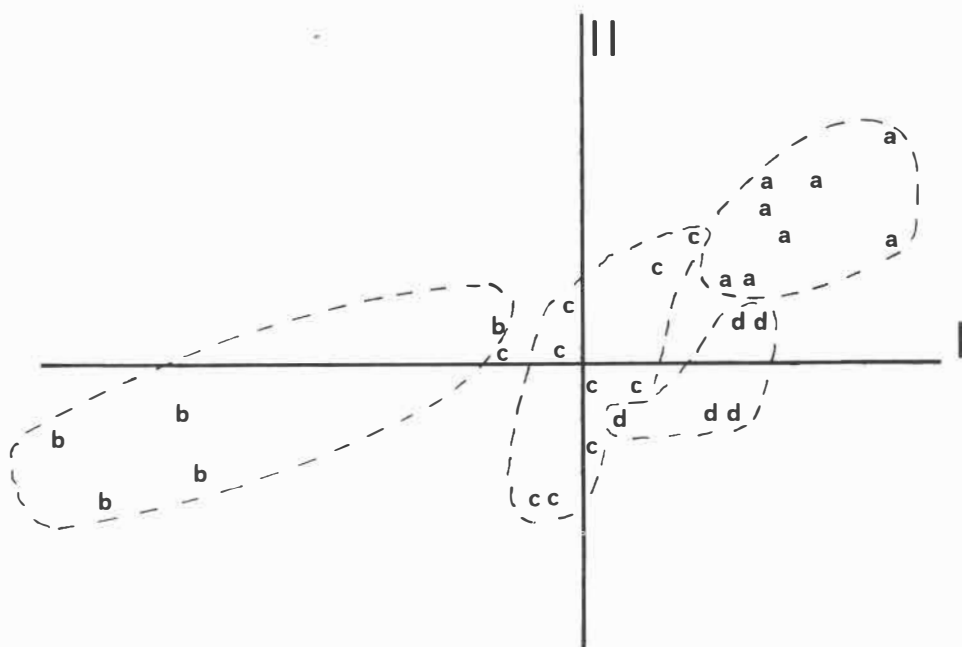


Fig. 12 — Ordination of deposimetric stations on the basis of the data in Tab. 3. Letters refer to station groups obtained by numerical classification of the same data set (see text).

(station group a). The distribution of the stations included in the four groups within the survey area is as follows:

- group a: this group includes the stations with less pollution. They are all distributed within an area roughly corresponding to the distribution area of releve group 5.
- group b: the stations included in group b have the highest pollution values. With the exception of station Nr. 5, they are all located in a narrow area in the industrial zone of Trieste.
- groups c, d: the stations in these groups have pollution values that are intermediate between those of the stations of group a and the stations of group b. They are mostly located in the lichen desert zone, between the distribution areas of the stations of groups a and b.

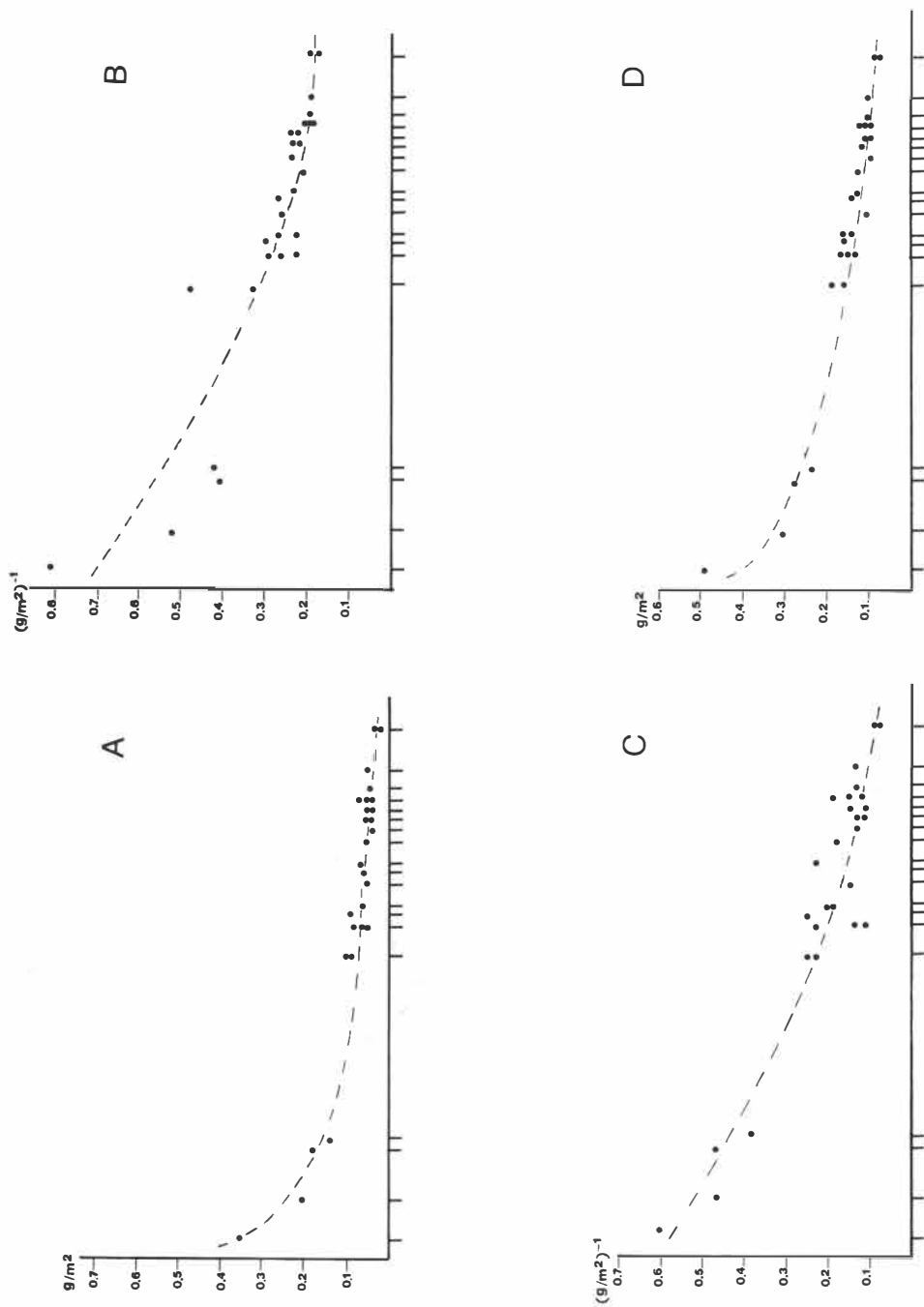
Zonation of the town and indicator species

Fig. 14 shows a subdivision of the urban area of Trieste in six zones. Such a zonation is based on the results of the analysis of both floristic and pollution data. Of the six zones, three are defined by the occurrence of a certain type of lichen vegetation (1, 2, 3), three by given range of pollution (b, c, d; in the following the pollution levels are expressed as total fallout), as follows:

- Zone b: it is the most polluted zone; it coincides with part of the industrial area of Trieste (group of deposimetric stations b). Trees are completely devoid of lichens. Mean pollution level is $0.86 \text{ g/m}^2/\text{day}$.
- Zone c: the pollution is much lower than in the previous zone (average $0.29 \text{ g/m}^2/\text{day}$): it occupies a belt surrounding zone b.
- Zone d: the pollution levels are slightly lower than those recorded in the stations of zone c (average $0.22 \text{ g/m}^2/\text{day}$). Also this zone is mostly located within the lichen desert, surrounding zone c.
- Zone 1: this zone is characterized by the prevalence of releves of group 5. Lichens are mainly present at the base of the boles. The zone includes most of the deposimetric stations of group a. The pollution level at which lichens begin to appear averages $0.20 \text{ g/m}^2/\text{day}$.
- Zone 2: this zone is characterized by the prevalence of releves of group 4. Lichens are present both at tree base and at 1.5 m on the bole. No data on air pollution are available, but this should be under $0.20 \text{ g/m}^2/\text{day}$.
- Zone 3: this zone is characterized by the prevalence of releves of groups 1 (in woody stands) or 2 (on isolated trees), more rarely releves of group 4 still occur at the S-side of isolated wayside trees. Lichens are abundant both at tree base and at 1.5 m on the boles. No pollution data are available.

It is also possible to define the zones 1, 2 and 3 by the presence of some easily recognizable species (indicator species). Fig. 15 shows the frequency distributions of selected species in the releves groups (the latter are arranged according to the projection of their centroids on the rotated first axis of Fig. 6, see also Fig. 9).

- Zone 1: the only indicator species for this zone are *Physcia adscendens*, *Physcia orbicularis* and (weakly) *Physcia aipolia* (Fig. 15a). They occur also in the



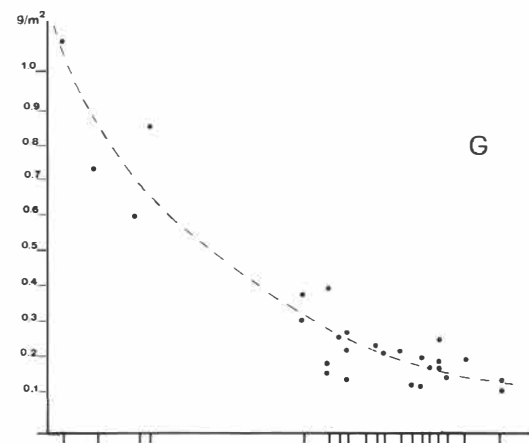
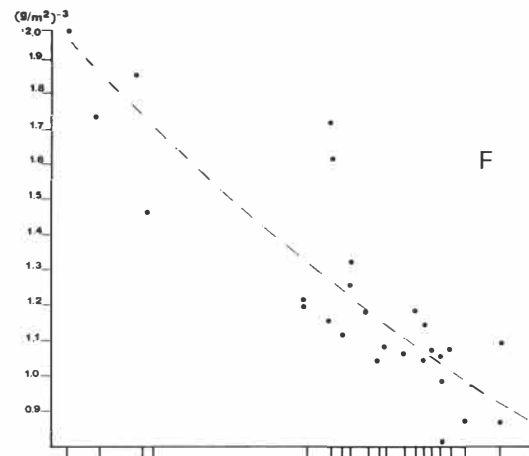
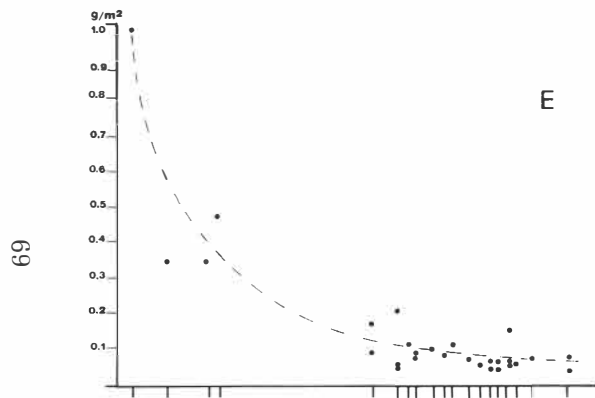


Fig. 13 —

Direct interpretation of the ordination of deposimetric stations (see Fig. 12). The x-axis reports the scores of each station on the first Principal Component in the ordination of Fig. 12; the y-axis refers to the amount of pollutants in each station. Each graph refers to a single pollutant, labelled with a capital letter, as follows: A) Soluble substances, B) Sulphates; C) Calcium, D) Ashes of soluble substances, E) Ashes of insoluble substances; F) Magnesium; G) Total fallout.

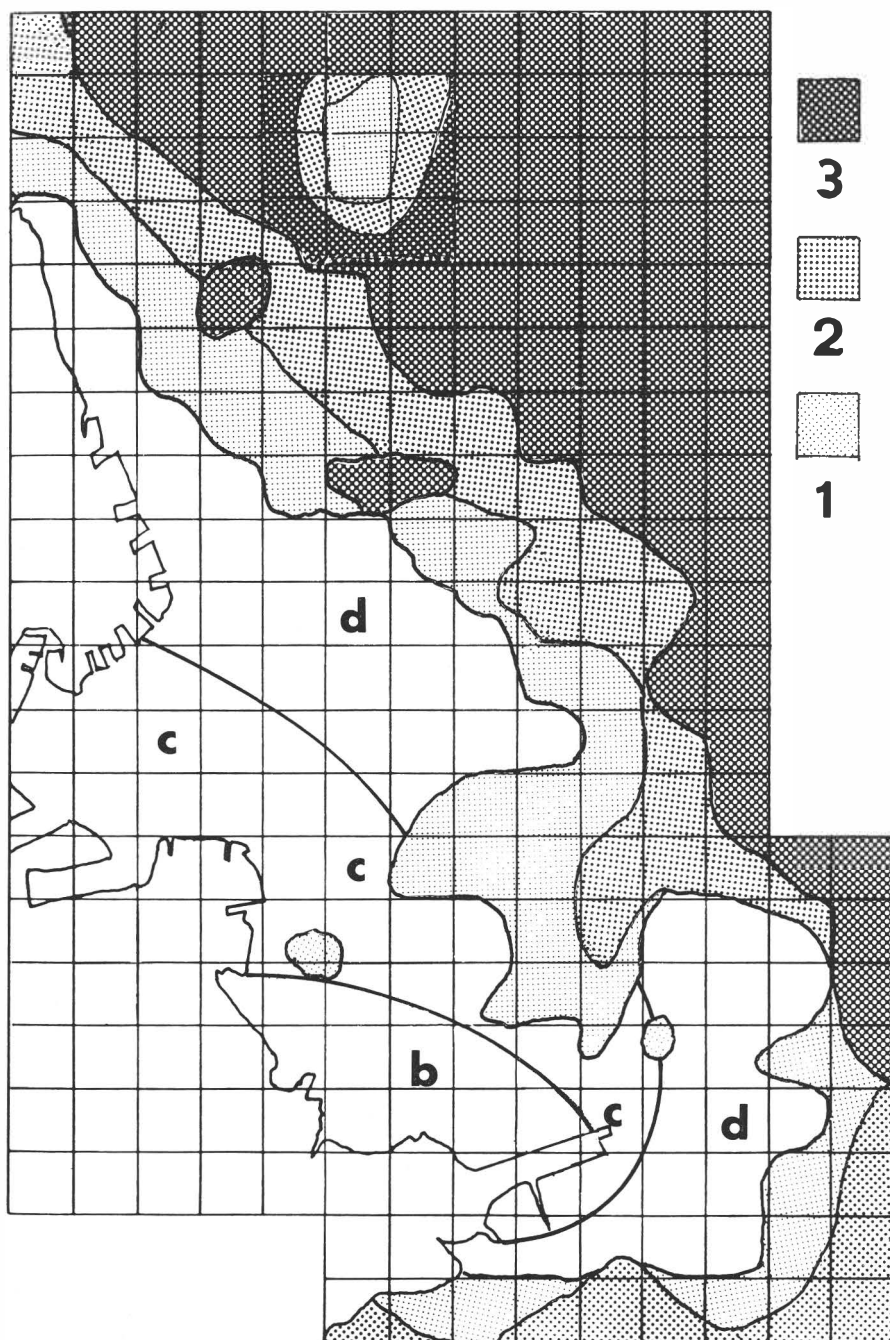


Fig. 14 — Zonation of the survey area, based both on floristic and pollution data (see text).

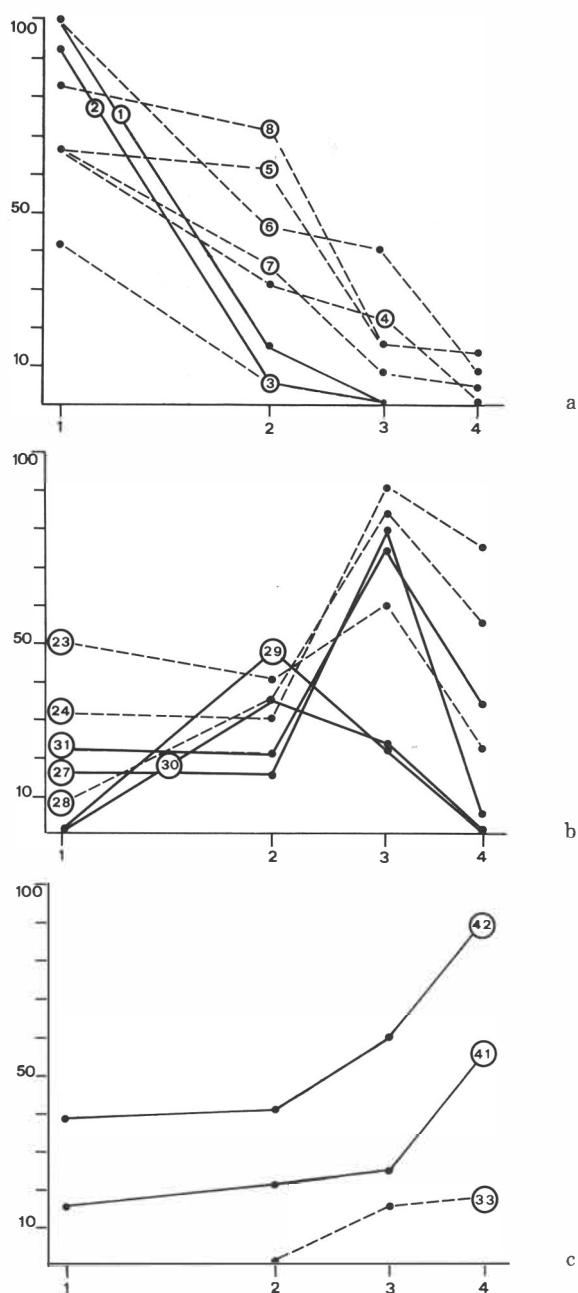


Fig. 15 — Identification of indicator species for four relevé groups. The x-axis reports the scores of the centroids of relevé groups 1, 2, 3 and 4 on the rotated first axis of the ordination of relevés based on floristic data (see Fig. 6), the y-axis refers to the frequency of each species in the relevé groups. Species are identified by circled numbers (as in Tab. 1). a) indicator species of relevé group 1; b) indicator species of relevé groups 2 and 3; c) indicator species of relevé group 4.

other zones; zone 1 is defined by their being the most abundant lichens at tree base when the trunks are completely devoid of lichens.

Zone 2: the best indicator species for zone 2 are: *Lecanora chlarotera* and *Candelaria concolor*. *Xanthoria parietina* and *Physcia biziana* may be used as indicator of this zone if present at 1.5 m on the bole of the tree. (Fig. 15b)

Zone 3: *Evernia prunastri*, *Hypogymnia physodes* and *Usnea hirta* are good indicator species for stands in light woods. Other indicator species, frequent also on isolated trees are: *Parmelia subaurifera*, *Parmelia caperata*, *Parmelia sulcata*, *Parmelia tiliacea* and *Parmelia subrudecta* (Fig. 15c).

Since the zones 1, 2 and 3 are respectively located at increasing distance from heavily urbanized areas, the indicator species may be considered as being mentioned in order of increasing poleophoby.

Discussion and Conclusions

Most authors agree that air pollution is the main factor influencing the distribution of lichens in urban areas. According to Rydzak (1969), however, the drier climate of urbanized areas should also be taken into account as another main factor influencing the distribution of lichens. In my opinion, both factors should be taken into consideration when interpreting distribution patterns of lichens around towns, and the relative importance of drought should be expected to increase with increasing aridity of the general climate. It is perhaps not a case that most of the authors that expressed themselves against Rydzak's views were from Western Europe (oceanic climate), and that Rydzak himself was working in continental Poland.

The results of the present study are difficult to interpret on the sole basis of the pollution hypothesis. From the periphery to the center of Trieste there is an increase in the frequency of xerophytic, nitrophytic and neutro-basiphytic species. If pollution alone would be the main factor affecting lichen distribution in the Trieste area, one should expect an increase in acidophytic species (secondary acidification of the bark by air pollution) towards the most polluted areas. Trieste has a rather dry climate (see Fig. 1); although direct data on the urban microclimates of Trieste are not available, another fact that characterizes the climate of Trieste as relatively dry is the extremely low frequency of *Lecanora conizaeoides* within the town. This species is the most toxitolérant lichen which occurs on trees (Laundon, 1973), and its distribution considerably enlarged in the last century, above all in Northwestern Europe (suboceanic conditions). Nimis (1986) found it abundantly in Udine, that has a more humid climate than Trieste, whereas in Trieste it was present only on two trees in the Jewish Cemetery, which were growing in a very shady site, at the N-side of a high wall. It seems that in Trieste drought could have an influence in the distribution of lichens: in the study area most of the available xerophytic epiphytes are also neutro-basiphytic (*Xanthorion*-species): they can stand the drier climate of the urbanized area, but cannot survive on acid bark. This is why towards the center they are mostly restricted to tree bases, where the pH is around 7.0

(secondary eutrophication by dust and nitrates); although they are mostly photophytic, in the urban environment they tend to be limited at the North exposed side of the trunks, where evapotranspiration is lower. At the other side, most of the acidophytic species present in the area are also rather hygrophytic (*Parmelietales*-species): they find their optimal development in the *Quercus*-woods surrounding the town, where both low pH (*Quercus* bark is normally acid) and higher air humidity are available. The acid bark of trees within the urban area is not colonized by any lichens; the reason is probably that the pH is too low for *Xanthorion*-species and air humidity is too low for *Parmelietales*-species. The explanatory model presented above should be compared with the one proposed by Nimis (1986) for the town of Udine, located less than 100 Km far from Trieste, where the climate is more humid and the distribution patterns of lichens are very different from those recorded in Trieste.

Riassunto

Viene studiata la distribuzione dei licheni nell'area urbana di Trieste. Lo studio si basa su 213 rilievi fitosociologici di vegetazione lichenica epifita, e sui dati di inquinamento relativi a 28 stazioni deposimetriche. I risultati della classificazione numerica dei rilievi permettono di individuare quattro tipi vegetazionali principali, caratterizzati da diversi gradi di poleofobia. L'ecologia dei quattro gruppi di rilievi è stata studiata sulla base sia di misure dirette di pH, sia degli indici di tolleranza a pH, luce, aridità e nitrati, attribuiti a ciascuna specie da Wirth (1980). Dalla periferia al centro della città si ha una diminuzione del numero assoluto di specie, ed un aumento della frequenza relativa di specie xerofitiche, neutrobasifitiche, fotofitiche e nitrofitiche. Tali risultati non sembrano interpretabili considerando il solo inquinamento atmosferico come fattore ecologico principale. La maggiore aridità nell'ambito delle zone fortemente urbanizzate sembra essere un fattore limitante di notevole importanza per la crescita dei licheni. I risultati permettono di suddividere l'area urbana di Trieste in sei zone: tre sono definite dalla presenza di determinate specie di licheni, le rimanenti vengono delimitate in base a dati di inquinamento.

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