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URBAN LICHEN STUDIES IN ITALY II: THE TOWN OF UDINE*

STUDI SUI LICHENI IN AMBIENTE URBANO. II: LA CITTÀ DI UDINE

Abstract — This paper reports on the distribution of lichen species in the urban environment of Udine (NE-Italy). The study is based on 167 phytosociological releves, taken on trees with eutrophic bark (mainly *Populus*). These have been submitted to numerical classification and ordination. Four main releve groups have been recognized, disposed more or less concentrically around the town center. The ecology of the releve groups has been analyzed on the basis of the indicator values associated by WIRTH (1980) to each species. Acidophytic species increase towards the center of the town. The main factor affecting lichen distribution in the town of Udine seems to be air pollution.

Key words: Air pollution, Lichens, Udine.

Riassunto breve — Il lavoro tratta della distribuzione dei licheni nell'ambiente urbano di Udine (Italia nord-orientale). Lo studio è basato su 167 rilievi di vegetazione lichenica epifita su alberi a scorza eutrofica (soprattutto pioppi). Questi sono stati sottoposti a programmi di classificazione ed ordinamento. Quattro gruppi principali di rilievi sono stati individuati, la cui distribuzione è più o meno concentrica attorno al centro cittadino. Le specie acidofile aumentano verso il centro. Il principale fattore che influenza la distribuzione dei licheni nell'area di studio sembra essere l'inquinamento atmosferico.

Parole chiave: Licheni, Inquinamento, Udine.

Introduction

Urban areas are extreme environments for most lichens: the number of species drastically decreases towards town centers and most species show a progressive decline

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in cover, size and shape of the individual thalli from the periphery to the center of towns (SEAWARD, 1976). These effects have been often attributed to air pollution (for a review of the abundant literature on this subject see FERRY et al., 1973; GUDERIAN, 1985). The drier climate in urbanized areas was put forward as a main factor affecting lichen distribution by RYDZAK (1969), but his «Drought Hypothesis» has been strongly criticized by several authors (see COPPINS, 1973).

The study of lichens in urban environments implies several lines of research, from field studies on the distribution and morphology of lichen species, to transplant experiments and to laboratory studies on the physiology of lichen thalli in situations simulating the conditions prevailing in an urban environment. The analysis of the distribution patterns of lichen species around a town is often the first preliminary step towards further studies aiming to test working hypotheses originating from the results of field work. Zone-maps based on the distribution of lichens have been constructed for individual industrial plants, towns, cities, provinces and even whole countries (for a review, see HAWKSWORTH, 1973), above all in Western and Northern Europe, and in North America. Most of these studies have been carried out with the aim of using lichens as indicators of air pollution, and different methods have been developed to assess the levels of pollution on the basis of lichenological data (see FERRY et al., 1973). In contrast to what happened in most countries of Europe, in Italy little has been published regarding the study of lichens in urban environments. The only papers dealing with lichens and air pollution refer to rather small villages in mountain areas (CANIGLIA et al. 1978; PIERVITTORI & MONTACCHINI, 1980; SPAMPANI, 1982).

This paper is the second 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 concern the distribution of lichens in three Italian towns characterized by different climates: Trieste (NIMIS, 1985), Udine (this paper) and Rome (NIMIS, 1987, in prep.). I would like to stress at the beginning that the main aim of the three mapping studies is simply the analysis of the distribution of lichens in the three towns. Hypotheses on the role of pollution or of climate in determining the distribution patterns of lichen species are made in each paper, but no statement follows about an inference of pollution levels from the distribution of lichens. The main reason for this is that the available methods (above all the sensitivity scales) have been worked out in areas whose climate, and to some extent, whose lichen floras, greatly differ from those of the investigated Italian towns. The acritical application of poleophoby scales such

as the ones of BARKMAN (1958) or HAWKSWORTH & ROSE (1970) is likely to produce confused and not reliable results. Sensitivity values can be associated to the various species only after a careful investigation of the area to be surveyed (DE WIT, 1976), and their extrapolation to other areas is not always justified. The first three papers of this series aim at providing the basic information to test the possibility of constructing poleophoby scales reflecting situations prevailing in Italy. Sensitivity values to air pollution could be worked out only on the basis of further studies on the relations between distribution patterns of lichens and patterns of air pollution in the same areas. This point is out of the aims of this paper.

Description of the survey area

The town of Udine is located in NE-Italy, at Lat. 44°00' N, Long. 13°15' E, at 136 m on sea level. The population is of ca. 100.000 people. The town lies in the high Friulian Plain, of flat terrain (except for the hill of the castle, in the middle of the town). No stands of relatively undisturbed vegetation are present in the urban area of Udine, since the outskirts of the town have been heavily exploited for

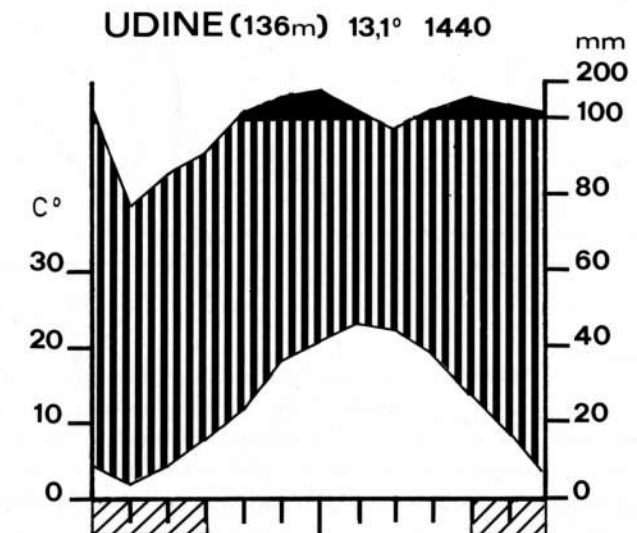


Fig. 1 - Climatic diagram of Udine.
- Diagramma climatico di Udine.

agriculture. The lichen vegetation in the surroundings of the town has been studied by NIMIS & DE FAVERI (1981).

The climatic diagram of the town is in fig. 1. Mean yearly precipitation is 1440 mm, mean yearly temperature $13,1^{\circ}\text{C}$. The yearly termical excursion is of $18,2^{\circ}\text{C}$ (GENTILLI, 1964), much lower than the average in the Po Plain, that is around 20°C . The mean temperature deviation between autumn and spring is also rather small ($1,2^{\circ}\text{C}$), whereas the termic anomaly is $4,5^{\circ}\text{C}$ (GENTILLI, 1964), one of the highest recorded over the Italian territory. Yearly average air humidity is 69% (POLLI, 1971). The main winds blow from the East and the North (fig. 2).

Data and Methods

A reference grid with squares of 500 m has been superimposed to the map of Udine (see fig. 3). In each square epiphytic lichen vegetation has been recorded. The choice of porophytes was particularly troublesome. The central part of the town has many green areas, with a wide variety of porophytes, whereas the outskirts are in-

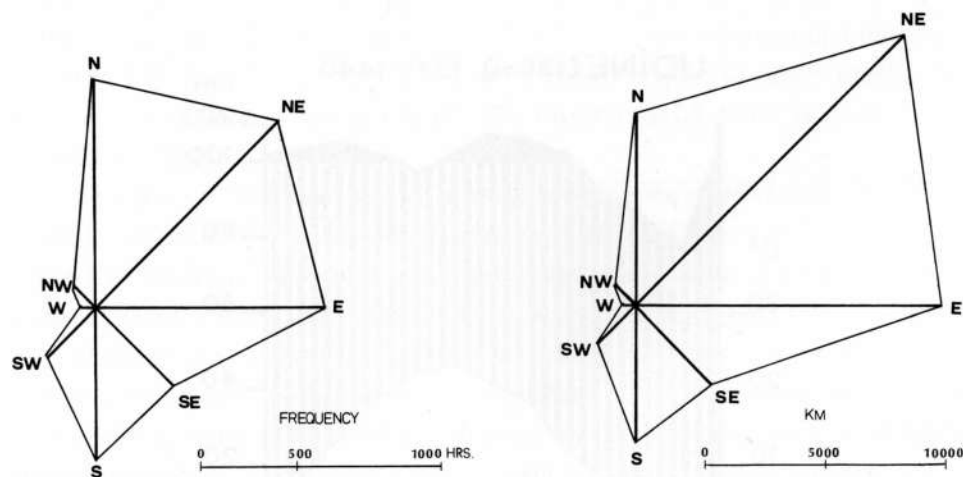


Fig. 2 - Average yearly wind speed and wind frequency in the town of Udine (redrawn from POLLI, 1971).

- *Frequenza in ore e Km percorsi in un anno dai singoli venti nella zona di Udine* (da POLLI, 1971).

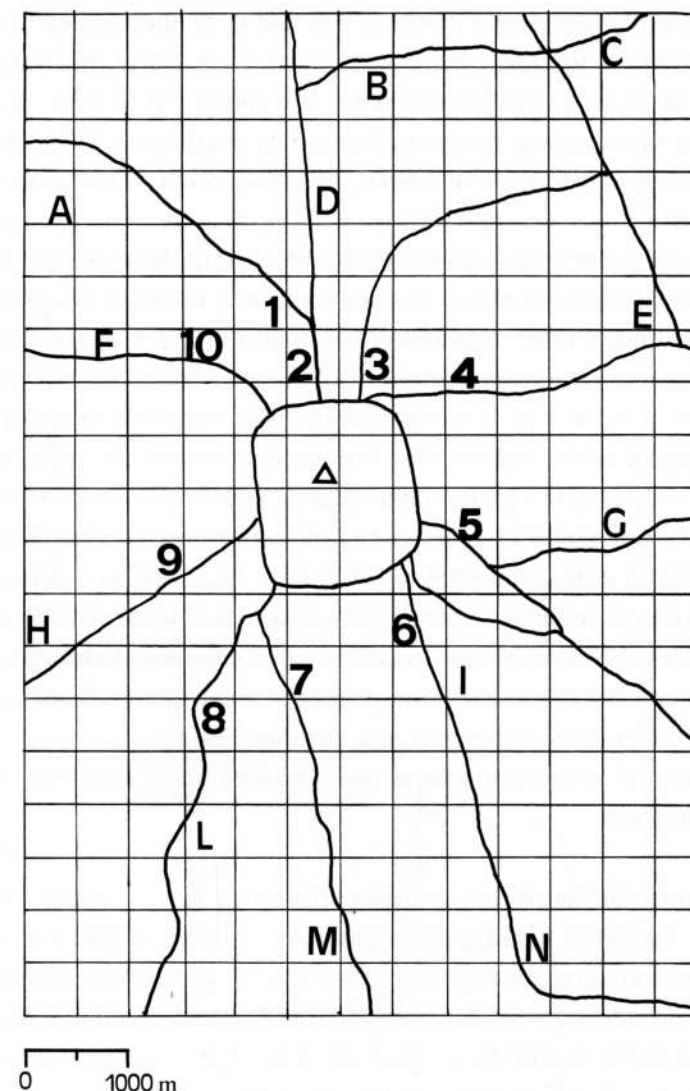


Fig. 3 - Map of Udine with reference grid (see figs. 9 and 12).

- *Carta della città di Udine con griglia di riferimento* (v. figg. 9 e 12).

Main roads — *Strade principali*: 1) Via Colugna, 2) Viale Volontari della Libertà, 3) Via Gorizia, 4) Via Cividale, 5) Via Buttrio, 6) Viale Palmanova, 7) Via Lumignacco, 8) Via Pozzuolo, 9) Viale Venezia, 10) Via Martignacco.

Main Localities - *Frazioni principali*: A) Rizzi, B) Molin Nuovo, C) Godia, D) Padermo, E) S. Gottardo, F) Villaggio del Sole, G) Laipacco, H) S. Caterina, I) Baldasseria, L) S. Osvaldo, M) Cassinis, N) Paparotti.

tensely exploited for agriculture, and the number of available trees is limited. A preliminary survey showed that in the outer area, the only tree that was present in almost all of the squares was *Populus nigra*. This forced the selection of trees with eutrophic bark as porophytes to be sampled throughout the area. Of the 167 relevés, 112 were taken on *Populus*, 21 on *Ulmus*, 19 on *Sambucus*, 7 on *Juglans* and 8 on *Tilia* (the latter only in quadrants where none of the other trees was present). Relevés were taken at the North and South sides of the boles, at the base and at 1.5 m height, within quadrats of 50 cm. In at least 50 % of the squares there was just one porophyte suitable for sampling, and in the others no significant differences were observed in the epiphytic vegetation of contiguous trees of the same species. One porophyte was sampled in each square. The potential number of relevés (4 for each tree, and one tree for each of the 247 squares) is 988. The actual number is 167, since, apart from the lichen desert zones, 88 squares did not have suitable porophytes and in most of the remaining ones epiphytic lichens were often present only at the North side of the bole, and either only at the base or only at 1.5 m. 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 sample. Sampling was carried out in the months of September and October 1984.

The matrix of species and relevés was submitted to the following methods of multivariate analysis:

- 1) Classification of the relevés, to detect relevé groups with similar species composition. Complete Linkage Clustering (ANDERBERG, 1973) was used, with binary data and Correlation Coefficient (see ORLOCI, 1978) as resemblance measure.
- 2) Reciprocal Ordering of species and relevés, to detect eventual trends in compositional variation and to extract a limited number of indicator species. In this case program PCAB of WILDI & ORLOCI (1983) was used.

A further data source are the indicator values associated to each species by WIRTH (1980): they refer to four main factors: pH, light, moisture and concentration of nitrogen. By multiplication of the matrix of species and relevé groups by the matrices of species and indicator values, four tables have been obtained, containing the relative frequencies of the various classes of pH, light, moisture and concentration of nitrates in the relevé groups obtained by classification, calculated over the total occupancies of the species in each relevé group. These matrices have been

separately submitted to Concentration Analysis (AOC, see FEOLI & ORLOCI, 1979) in order to give an indirect ecological characterization of the relevé groups.

Results

The number of relevés is 167, the number of species 36. The results of the classification are shown in the dendrogram of fig. 4. At a value of the Correlation Coefficient of 0.20, 4 main relevé groups are formed. Tab. I reports the relative frequencies of the species in the 4 relevé groups. On the basis of floristic composition, these may be briefly characterized as follows:

Group 1: it includes species-poor relevés (mean number of species 2.5, total number of species 13), defined by species that mostly characterize the Foederatio *Xanthorion parietinae*. Constant species is *Physcia adscendens*, other frequent species are *Candelaria concolor*, *Physcia orbicularis* and *Scoliciosporum chlorococcum*. The cover is generally less than 20%. Damaged thalli have been frequently observed, particularly in the most

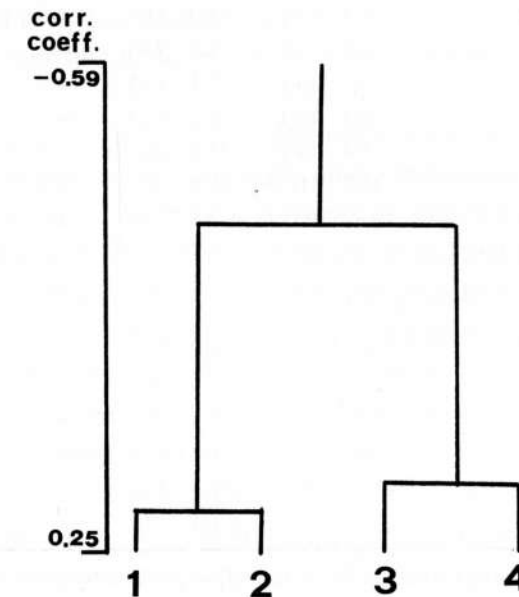


Fig. 4 - Dendrogram of relevés (numbers refer to relevé groups).
- Dendrogramma dei rilievi (i numeri si riferiscono ai gruppi di rilievi).

SPECIES	RELEVE GROUP NUMBER			
	1	2	3	4
<i>Hypogymnia physodes</i>	— —	— —	46.6 (+)	20.0 (+)
<i>Parmelia sulcata</i>	— —	— —	100.0 (1)	10.0 (+)°
<i>Lecanora conizaeoides</i>	4.6 (+)°	— —	46.6 (+)	60.0 (3)
<i>Parmelia exasperatula</i>	— —	— —	20.0 (1)	— —
<i>Ramalina fastigiata</i>	— —	— —	6.7 (+)°	— —
<i>Parmelina tiliacea</i>	— —	— —	6.7 (+)°	10.0 (+)°
<i>Pseudevernia furfuracea</i>	— —	— —	6.7 (+)°	— —
<i>Candelariella xanthostigma</i>	— —	— —	6.7 (+)	— —
<i>Evernia prunastri</i>	— —	— —	26.7 (+)°	— —
<i>Usnea hirta</i> gr.	— —	— —	20.0 (+)°	— —
<i>Parmelia caperata</i>	— —	— —	20.0 (1)	— —
<i>Parmelia subaurifera</i>	— —	— —	46.6 (1)	— —
<i>Scoliciosporum chlorococcum</i>	18.2 (+)	— —	80.0 (1)	90.0 (1)
<i>Candelaria concolor</i>	36.4 (1)	85.7 (2)	3.3 (+)	— —
<i>Physcia orbicularis</i>	25.0 (2)	95.2 (1)	6.7 (+)°	— —
<i>Physciopsis adglutinata</i>	4.6 (+)	54.8 (2)	— —	— —
<i>Xanthoria parietina</i>	15.9 (+)°	71.4 (2)	6.7 (+)°	— —
<i>Physcia stellaris</i>	— —	9.6 (+)	— —	— —
<i>Physcia labrata</i>	— —	2.3 (+)	3.3 (+)°	— —
<i>Physcia adscendens</i>	100.0 (1)°	88.0 (2)	33.3 (+)°	— —
<i>Parmelia subrudecta</i>	11.4 (+)°	25.0 (2)	6.7 (+)°	— —
<i>Caloplaca cerina</i>	4.6 (+)	4.7 (+)	— —	— —
<i>Physcia tenella</i>	2.3 (+)	7.1 (+)	— —	— —
<i>Caloplaca holocarpa</i>	2.3 (+)	4.7 (+)	— —	— —
<i>Lecanora chlorotera</i>	6.8 (+)	23.8 (1)	3.3 (+)	— —
<i>Lecidella elaeochroma</i>	13.7 (1)	28.5 (1)	20.0 (+)	— —
<i>Lecanora subfuscata</i>	— —	7.1 (+)	6.7 (+)	— —
<i>Buellia alboatra</i>	— —	4.7 (+)	— —	— —
<i>Lecanora hageni</i>	— —	7.1 (+)	— —	— —
<i>Arthonia radiata</i>	— —	9.5 (+)	— —	— —
<i>Caloplaca ferruginea</i>	— —	4.7 (+)	— —	— —
<i>Candelariella reflexa</i>	— —	2.3 (1)	— —	— —
<i>Buellia punctata</i>	— —	4.7 (+)	— —	— —
<i>Catillaria nigroclavata</i>	— —	2.3 (+)	— —	— —
<i>Lecania cyrtella</i>	— —	7.1 (+)	— —	— —
<i>Candelariella aurella</i>	— —	2.3 (+)°	— —	— —

Tab. I - Relative frequencies of species in the releve groups. Symbols in brackets refer to average cover, expressed according to the BRAUN-BLANQUET (1964) scale.
 - Frequenze relative delle specie nei gruppi di rilievi. I simboli tra parentesi si riferiscono alla copertura media, espressa secondo la scala di BRAUN-BLANQUET (1964).

common species, *Physcia adscendens*. Mostly at tree base, N-exposed.

Group 2: also this group is mostly characterized by *Xanthorion*-species, with the difference that the total number of species is much higher than in group 1 (23), as it is the mean species number (5.6). High frequency - species are: *Physcia orbicularis*, *Physcia adscendens*, *Candelaria concolor*, *Xanthoria parietina* and *Physciopsis adglutinata*. They cover always more than 60% of the boles. Mostly at 1.5 m on the bole, both S- and N- exposed.

Group 3: this group mostly includes releves characterized by species of the *Parmelietales physodo-tubulosae* Order. Although both the total and the mean number of species are relatively high (22 and 5.3 respectively), many of them had poorly developed or damaged thalli, the total cover never going over 20%, and only two species were present in more than the half of the releves: *Parmelia sulcata* and *Scoliciosporum chlorococcum*. Mostly at 1.5 m on the boles, N- exposed.

Group 4: this group is characterized by the high frequency of *Scoliciosporum chlorococcum* and *Lecanora conizaeoides*, that often are the only species present in the releves (average species number 1.9). *Lecanora conizaeoides* may cover up to 60% of the surface. Some *Parmelietales*-species are occasionally present, always with poorly developed and damaged thalli. Both at tree base and at 1.5 m, with a slight prevalence (60%) of N-exposed stands.

Summarizing, the results of the numerical classification of the releves show that three main epiphytic community types might be recognized in the study area: the first (releve group 2) fairly well corresponds with the *Physcietum elaeinae candelariosum* (NIMIS & DE FAVERI, 1981), the second (releve group 3) with the *Parmelia* spp.vv.-society described by NIMIS (1982) for the Trieste Karst. The third (releve group 4) is a «community» dominated by *Lecanora conizaeoides*, that has been called *Lecanoretum conizaeoidis* (DUVIGNEAUD, 1942) (Syn.: *Lecanoretum pityrae*, BARKMAN, 1958). Relve group 1 is clearly an impoverished form of the community typically represented by releve group 2.

Tab. II reports the frequency distributions of the classes of ecological indexes (from WIRTH, 1980), in the 4 releve groups, calculated on the total occupancies of each releve group. The indexes concern species tolerance to: pH (8 classes, tab. IIa), light (4 classes, tab. IIb), nitrogen (4 classes, tab. IIc), water (4 classes, tab. IId). The data of tab. II have been separately submitted to AOC, in order to characterize

ecologically the 4 releve groups, and detect possible ecological gradients. The results are discussed in the following.

CLASSES OF ECOLOGICAL INDEXES (WIRTH, 1980)			RELEVE GROUP NUMBER			
			1	2	3	4
a)						
A)	pH	under 3.3	9.4	—	28.0	27.7
B)	pH	3.4 - 4.8	9.4	—	57.3	39.8
C)	pH	4.1 - 4.8	14.1	7.7	89.9	99.9
D)	pH	4.9 - 5.6	78.3	49.7	73.2	99.9
E)	pH	5.7 - 7.0	85.8	91.8	14.0	61.1
F)	pH	around 7.0	66.0	55.3	12.7	—
G)	pH	7.1 - 8.0	65.0	54.0	3.8	—
H)	pH	above 8.0	1.0	9.0	—	—
b)						
A)	rather	skiophytic	—	1.7	—	27.7
B)	little	skiophytic	16.0	15.0	69.5	99.9
C)	rather	photophytic	99.0	99.1	99.9	72.2
D)	very	photophytic	75.5	60.7	36.3	—
c)						
A)	not	nitrophytic	16.9	14.6	62.4	38.8
B)	little	nitrophytic	39.6	54.9	88.5	99.9
C)	rather	nitrophytic	95.3	90.1	67.5	88.8
D)	very	nitrophytic	59.4	43.7	7.6	—
d)						
A)	very	hygrophytic	—	—	5.5	3.4
B)	rather	hygrophytic	26.2	18.6	82.0	94.4
C)	mesophytic		98.9	83.0	98.6	99.9
D)	rather	xerophytic	99.9	95.6	58.6	27.7

Tab. II - Relative frequencies of the classes of ecological indexes in the releve groups, calculated over the total occupancies in each group. a) pH, b) photophytism, c) nitrophytism, d) xerophytism.

- *Frequenze relative delle classi degli indici ecologici nei gruppi di rilievi, calcolate sul totale delle presenze in ciascun gruppo. a) pH, b) fotofitismo, c) nitrofitismo, d) xerofitismo.*

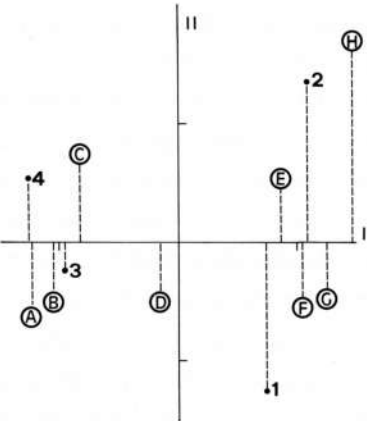


Fig. 5 - Arrangement of releve group- (numbers, as in tab. II) and of pH class- points (letters, as in tab. IIa) according to the first two Canonical Variates of AOC, performed on the data in tab. IIa).

- *Disposizione dei gruppi di rilievi (numeri, come in tab. II) e delle classi di pH (lettere, come in tab IIa), secondo le prime due variabili canoniche di AOC, sui dati di tab. IIa.*

CLASSES OF ECOLOGICAL INDEXES			Ist Can. Variate		IInd Can. Variate	
			x ²	%	x ²	%
A)	pH	under 3.3	43.7	7.34	0.362	1.73
B)	pH	3.4 - 4.0	84.2	14.15	0.348	1.85
C)	pH	4.1 - 4.8	168.0	28.23	2.205	11.72
D)	pH	4.9 - 5.6	3.4	0.57	1.148	6.10
E)	pH	5.7 - 7.0	121.8	20.47	1.060	5.63
F)	pH	around 7.0	73.0	12.26	0.820	4.36
G)	pH	7.1 - 8.0	89.9	15.10	0.636	3.38
H)	pH	above 8.0	11.0	1.84	12.254	65.18
RELEVE GROUPS						
Group No. 1			102.0	17.14	8.95	47.60
Group No. 2			169.1	28.40	8.66	46.00
Group No. 3			130.0	21.84	0.27	1.46
Group No. 4			194.0	36.95	0.99	5.29

Tab. III - Levels of influence of releve groups and pH- classes on the first two Canonical Variates of AOC, performed on the data in tab. IIa (see fig. 5).

- *Livelli di influenza dei gruppi di rilievi e delle classi di pH sulle prime due variabili canoniche di AOC (v. fig. 5).*

Fig. 5 shows the arrangement of pH-classes and releve group points according to the first two Canonical Variates of AOC. The levels of influence are in tab. III. The first Canonical Variate accounts for 95.7% of the total interaction chi square, the second for 3.03%. A clear pH-gradient is evident along the first variate. The sequence of the releve groups, in order of decreasing acidophytism is: 4, 3, 1, 2. Releve groups 4 and 3 are clearly acidophytic, whereas groups 2 and 1 are neutro- basiphytic.

Fig. 6 shows the arrangement of light tolerance classes and releve points according to the two first Canonical Variates of AOC. The levels of influence are in tab. IV. The first Canonical Variate accounts for 92.1% of the total interaction chi square, the second for 7.52%. Also in this case a clear gradient of photophytism is evident along the first variate, the sequence of the releve groups, in order of increasing

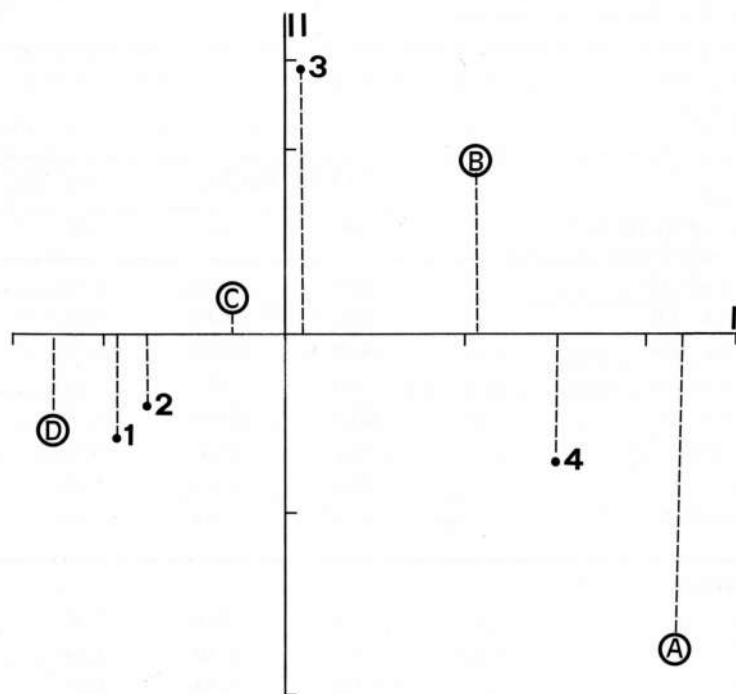


Fig. 6 - Arrangement of releve group- (numbers, as in tab. II) and of photophytism class-points (letters, as in tab. IIB) according to the first two Principal Components of AOC, performed on the data in tab. IIB.

- *Disposizione dei gruppi di rilievi (numeri, come in tab. II) e delle classi di fotofitismo (lettere, come in tab. IIB) secondo le prime due variabili canoniche di AOC, sui dati di tab. IIB.*

photophytism, is as follows: 1, 2, 3, 4. Releve groups 1 and 2 are characterized by the prevalence of photophytic species, releve group 4 of skiophytic species, whereas releve group 3 is in an intermediate position.

Fig. 7 shows the arrangement of nitrophytism classes and releve group points according to the two first Canonical Variates of AOC. The levels of influence are in tab. V. The first Canonical Variate accounts for 91.7% of the total interaction chi square, the second for 8.15%. The sequence of the releve groups along the gradient of increasing nitrophytism revealed by the first variate is as follows: 4, 3 (anitrophytic) and 2, 1 (nitrophytic).

Fig. 8 shows the arrangement of moisture-classes and releve group-points according to the first two Canonical Variates of AOC. The levels of influence are in tab. VI. The first Canonical Variate accounts for 94.9% of the total interaction chi square, the second for 5.02%. The sequence of the releve groups along the gradient of increasing xerophytism revealed by the first variate is as follows: 4, 3 (rather hygrophytic-mesophytic) and 1, 2 (xerophytic).

These results show a good correspondence between compositional and ecological characterization of the releve groups: the *Xanthorion* groups (1 and 2) show a

CLASSES OF ECOLOGICAL INDEXES	Ist Can. Variate		IInd Can. Variate	
	x ²	%	x ²	%
A) rather skiophytic	57.92	24.26	13.86	68.49
B) little skiophytic	88.26	37.28	4.21	20.80
C) rather photophytic	8.53	3.60	0.96	4.74
D) very photophytic	81.77	34.54	1.21	5.99
RELEVE GROUPS				
Group No. 1	53.9	22.77	1.30	6.70
Group No. 2	36.2	15.30	1.50	7.73
Group No. 3	0.6	0.20	14.20	73.20
Group No. 4	146.0	61.68	2.40	12.37

Tab. IV - Levels of influence of releve groups and photophytism classes on the first two canonical Variates of AOC, performed on the data of tab. IIB (see fig. 6).

- *Livelli di influenza dei gruppi di rilievi e delle classi di fotofitismo sulle prime due variabili canoniche di AOC (v. fig. 6).*

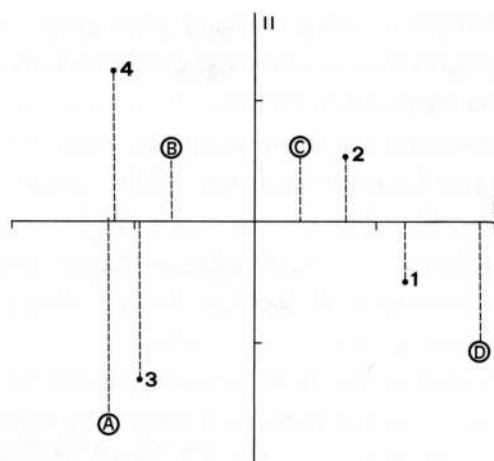


Fig. 7 - Arrangement of releve group- (numbers, as in tab. II) and of nitrophytism class- points (letters, as in tab. IIc) according to the first two Canonical Variates of AOC, performed on the data in tab. IIc.

- *Disposizione dei gruppi di rilievi (numeri, come in tab. II) e delle classi di nitrofitismo (lettere, come in tab. IIc) secondo le prime due variabili canoniche di AOC, sui dati di tab. IIc.*

CLASSES OF ECOLOGICAL INDEXES	Ist Can. Variate		IInd Can. Variate	
	χ^2	%	χ^2	%
A) not nitrophytic	30.37	19.56	8.11	58.98
B) little nitrophytic	24.70	15.91	1.56	11.34
C) rather nitrophytic	6.02	3.87	2.20	16.00
D) very nitrophytic	94.15	60.64	1.88	13.67
RELEVE GROUPS				
Group No. 1	59.9	38.64	0.76	5.55
Group No. 2	23.1	14.90	0.93	6.79
Group No. 3	39.5	25.16	6.25	45.40
Group No. 4	32.5	20.96	5.82	42.48

Tab. V - Levels of influence of releve groups and nitrophytism classes on the first two Canonical Variates of AOC, performed on the data in tab. IIc (see fig. 7).

- *Livelli di influenza dei gruppi di rilievi e delle classi di nitrofitismo sulle prime due variabili canoniche di AOC (v. fig. 7).*

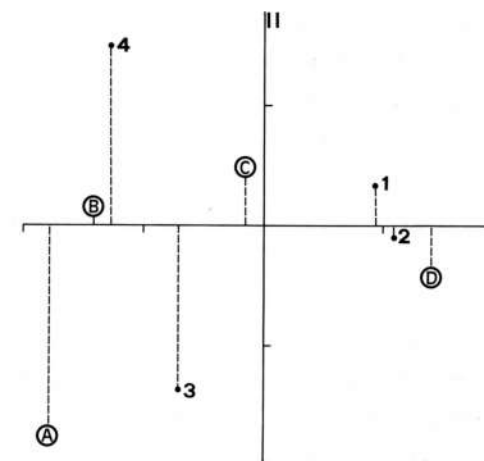


Fig. 8 - Arrangement of releve group- (numbers, as in tab. II) and of xerophytism class- points (letters, as in tab. IId) according to the first two Canonical Variates of AOC, performed on the data in tab. 2d.

- *Disposizione dei gruppi di rilievi (numeri, come in tab. II) e delle classi di xerofitismo (lettere, come in tab. IId) secondo le prime due variabili canoniche di AOC, sui dati di tab. IId.*

CLASSES OF ECOLOGICAL INDEXES	Ist Can. Variate		IInd Can. Variate	
	χ^2	%	χ^2	%
A) very hygrophytic	3.97	2.93	6.178	87.01
B) rather hygrophytic	69.14	51.87	0.008	0.11
C) mesophytic	0.00	0.00	0.606	8.50
D) rather xerophytic	60.13	45.20	0.308	4.33
RELEVE GROUPS				
Group No. 1	28.7	21.57	0.228	3.23
Group No. 2	37.7	28.34	0.000	0.00
Group No. 3	15.0	11.28	4.330	60.98
Group No. 4	51.5	38.72	2.520	35.49

Tab. VI - Levels of influence of releve groups and xerophytism classes on the first two Canonical Variates of AOC, performed on the data in tab. IId (see fig. 8).

- *Livelli di influenza dei gruppi di rilievi e delle classi di xerofitismo sulle prime due variabili canoniche di AOC (v. fig. 8).*

prevalence of xero- nitro- photo- and neutro-basiphytic species, whereas the *Parmelietales*- groups (3 and 4) have a prevalence of hygro- anitro- skio- and acidophytic species (particularly pronounced in group 4 that is always at one extreme of the gradients).

The distribution of the releve groups within the study area is shown in fig. 9 (a-d). In general, the 4 groups are concentrically distributed around the town center, as follows:

- Group 4: this group includes only 10 relevés, all taken within the area shown in fig. 9a (town center). This area shows both the quadrants with relevés of group 4 and those where trees did not have any epiphytic lichen (lichen desert). The reason is that in the very center of the town it was difficult to find suitable porophytes, because of the scarcity of trees and their being located immediately besides heavy traffic roads. It is therefore possible that the lichen desert areas would potentially sustain an epiphytic vegetation similar to that represented by releve group 4, if suitable habitats would be available.
- Group 3: distribution map in fig. 9b. The relevés of group 3 are mostly concentrically arranged around the area shown in fig. 9a.
- Group 1: distribution map in fig. 9c. The relevés of group 1 occupy an area that is located further away from the town center than the one of the relevés of group 3. They are mostly absent from the eastern part of the town.
- Group 2: distribution map in fig. 9d. The relevés of group 2 are those located in the outernmost portions of the town, particularly in its eastern and northern parts.

Summarizing, from the periphery to the center of the town the following trends are evident: increase in the relative frequencies of acido- skio- and xerophytic species, decrease of nitrophytic species.

The results of the reciprocal ordering of relevés and species are shown in fig. 10a (relevés) and fig. 10b (species). The releve points are arranged along a horse-shoe. At one extreme are the relevés of groups 2 and 3, at the other those of groups 1 and 4. By rotating the first axis of 45° the centroids of the releve groups are ordered according to a gradient of increasing poleophoby, with the centroids of releve groups 1 and 4 (center of the town and its surroundings) at one extreme, the centroid of releve group 2 (outernmost portion of the town) at the other extreme. The arrangement of the species points is shown in fig. 10b. Most of the species are located near the

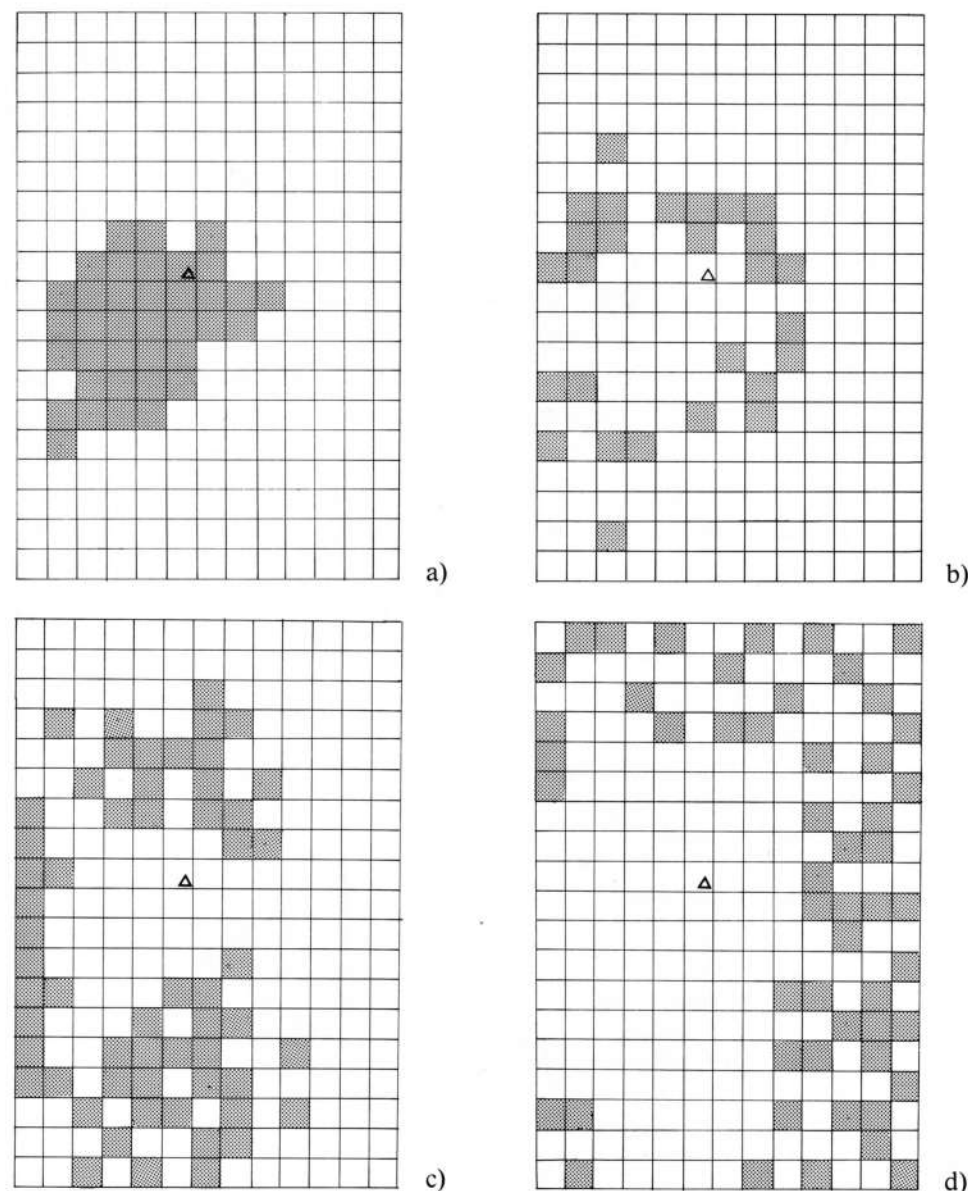


Fig. 9 - Distribution of releve groups in the survey area: a) group 4 and quadrants without epiphytic lichens, b) group 3, c) group 1, d) group 2. The triangle indicates the hill in the town center.

- Distribuzione dei gruppi di rilievi nell'area di studio: a) gruppo 4 e quadranti senza licheni epifiti, b) gruppo 3, c) gruppo 1, d) gruppo 2. Il triangolo indica la collina del castello.

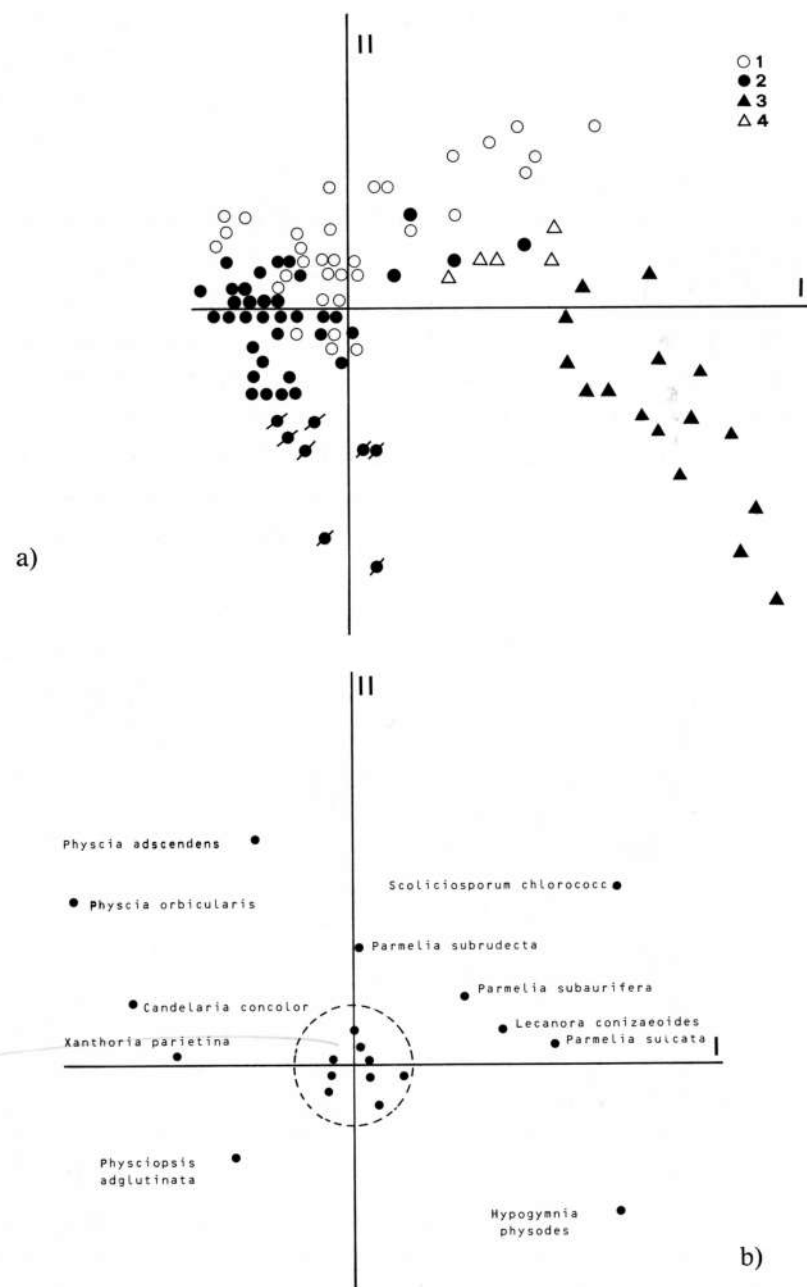


Fig. 10 - Reciprocal ordering of releves (a) and of species (b). (see also text).
- Ordinamento reciproco dei rilievi (a) e delle specie (b) (v. anche testo).

origin of the axes: these are either low frequency species, or species that are not significantly correlated with the arrangement of the releves in fig. 10a. 11 species, out of a total of 36, have high scores on the first or second axis: these may be taken as indicator species for the various releve groups, as follows:

Physciopsis adglutinata is a good indicator for releve group 2. The species has a rather high degree of poleophoby in the study area, being present only in the outern-most part of the town. A similar pattern is shown by *Xanthoria parietina* and, to a lesser degree, by *Candelaria concolor*. *Physcia orbicularis* and *Physcia adscendens* are good indicators for releve group 1: they tend to penetrate deeper into the urban environment. *Parmelia*-species and *Hypogymnia physodes* are restricted to a narrow area around the town center, and can be considered as indicators of releve group 3. The less poleophobic species are *Scoliciosporum chlorococcum* and *Lecanora conizaeoides*, present also within the center of the town (releve group 4). Fig. 11 reports species diversity-classes, superimposed to the ordination of releves: in general, species

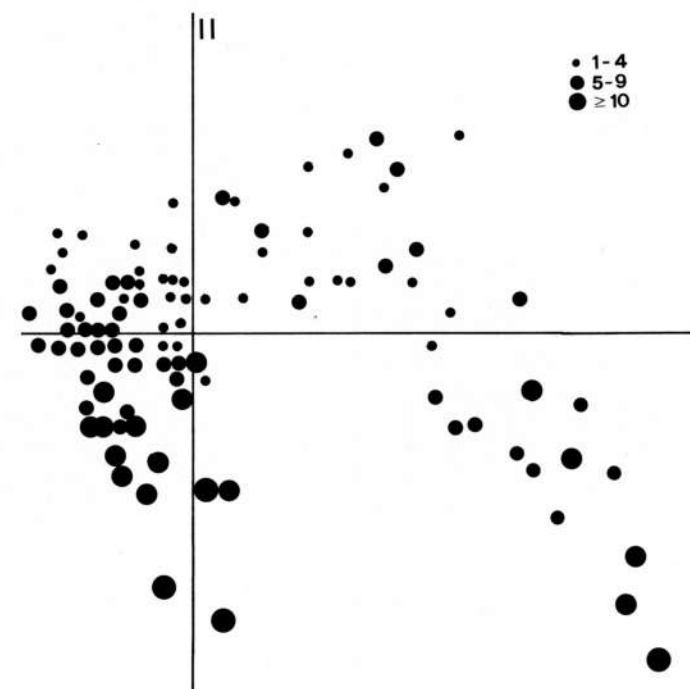


Fig. 11 - Diversity classes, superimposed to the ordination of releves, as in fig. 10.
- Classi di diversità, sovrapposte all'ordinamento dei rilievi, come in fig. 10.

diversity tends to decrease from the outskirts to the center of the town, with a remarkable exception in the relevés of group 3, mostly located around the town center

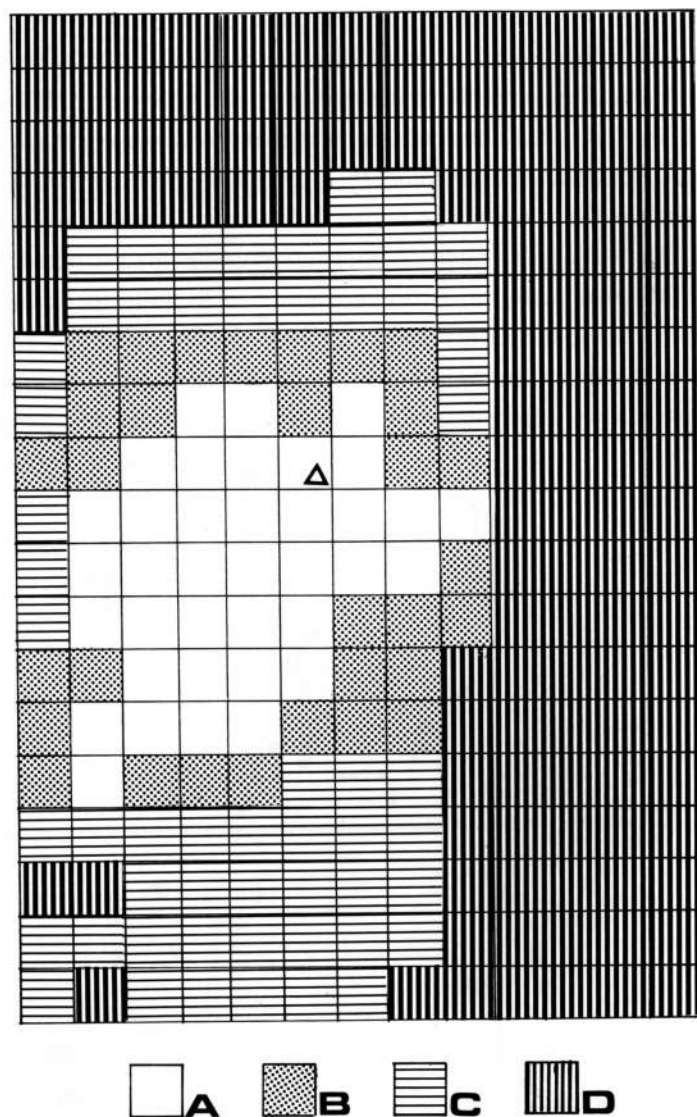


Fig. 12 - Lichen zones in the town of Udine, based on the distribution of the releve groups (see fig. 9 and text).
- Zonazione del territorio urbano di Udine, basata sulla distribuzione dei gruppi di rilievi (v. fig. 9 e testo).

and having a higher mean species number than the relevés of group 1. Such a situation has been reported also for other towns, like London (GILBERT, 1973) and Stockholm (SKYE, 1968). In the case of Udine, such an exception to the general rule of a progressive decline of lichen species towards town centers is probably due to the fact that the ring around the hearth of the town is the only area in which acid substrate is abundantly available (secondary acidification of *Populus*-bark, as a consequence of air pollution), providing a kind of «refuge» for acidophytic species (see also discussion).

The results presented above are summarized in fig. 12, that presents lichen zonation around the center of the town, based on the distribution of the releve groups obtained by numerical classification of the relevés: 4 main zones are recognized, as follows:

- Zone A: it is characterized by the absence of epiphytic lichens or by the presence of relevés included into group 4.
- Zone B: prevalence of relevés belonging to group 3, sometimes (rarely) together with relevés of group 4.
- Zone C: prevalence of relevés belonging to group 1, sometimes (rarely) with relevés belonging to group 3.
- Zone D: prevalence of relevés belonging to group 2, sometimes with relevés belonging to group 1.

Discussion and Conclusion

The first general remark on the results presented above concerns the relative degrees of poleophoby of the most frequently occurring species. BARKMAN (1958) proposed a poleophoby scale for lichens and algae, based on data from Northern and Western Europe. This scale has been used in mapping air pollution in several parts of Belgium (ISERENTANT & MARGOT, 1964; DE SLOOVER, 1964; DE SLOOVER & LE BLANC, 1968). Barkman's list includes many species that are absent from our study area, and in general there is little agreement between his scale and the relative poleophoby of the various species in the town of Udine. Just to give an example, *Parmelia tiliacea* is considered by BARKMAN as a rather poleophobic species, whereas in Udine it is most frequent all around the lichen desert. HAWKSWORTH & ROSE (1970) worked out a quantitative scale for the estimation of mean winter SO₂ air

pollution in England and Wales using epiphytic lichens (eutrophiated bark). Apart from the well known preference of *Lecanora conizaeoides* for polluted areas, also in this case there is little agreement with our results. Even the poleophoby scale worked out by NIMIS (1985) for the town of Trieste, located less than 100 km far from the town of Udine, agrees very little with the results of the present study. This fact is not surprising, since it is very improbable that similar species react the same way to urban environments with very different climatical conditions. The distribution of lichen species in an urban environment is a function not only of air pollution, but also of other factors (see GILBERT, 1970). According to LAUNDON (1973), from until 1866 to 1954, it had been assumed by most lichenologists that air pollution was the cause of lichen poverty in urban areas. Then, RYDZAK (1954, see also 1969) reported on a study of Lublin, in Poland, and concluded that dryness and not air pollution was the cause of the impoverishment of the lichen flora. Later studies by RYDZAK & KRYSIAK (1968, 1970) provided further evidence that toxic gases do not affect lichens, and that the «Drought Hypothesis» was the most probable. The conclusions of the Polish workers were strongly criticized, above all by lichenologists active in Western Europe (see BARKMAN, 1958, 1961, 1969; LAUNDON, 1967; HAWKSWORTH, 1971). The most detailed criticism to the «Drought Hypothesis» is provided by COPPINS (1973). The only study whose conclusions were in favour of the «Drought Hypothesis» was the one of BESCHEL (1958) on five Austrian towns. Although I find many of the arguments put forward by COPPINS (1973) against RYDZAK's views sound and scientifically correct, I totally disagree with his conclusion that «the presence of sulphur dioxide in the air can better explain the changes which have occurred in the lichen vegetation in both urban areas and the rural areas surrounding them». This «better» implies that we should use two alternative models for explaining lichen distribution in towns, one based on pollution, the other on dryness as the main factor affecting lichen growth, and that the first is «always» preferable to the second.

In my opinion, both air pollution and air humidity affect lichen distribution in urban environments, and the relative importance of the latter factor is likely to increase with increasing continentality of the climate. Perhaps it is not a chance that the «Drought Hypothesis» was accepted by people working in Poland and Austria, and rejected by most western european lichenologists. The differences in species distributions between the towns of Trieste and Udine provide a clear example of this fact. In Trieste, almost all of the species that in Udine penetrate deeply into the town

(species of releve group No. 3) have their optimum outside the town, whereas those that in Udine have the highest degree of poleophoby, in Trieste penetrate up to the border of the lichen desert. Trieste has a drier climate and is surrounded by a broad belt of natural oak woods. Udine has a more humid climate and is surrounded by cultivations. In Udine, acidophytic (and anitrophytic) species find few suitable substrates outside the town, since even trees with normally acid bark are affected by deposition of nitrates coming from manuring. Most acido- ad anitrophytic species in the area are also rather hygrophytic. The relatively humid climate of the town of Udine allows these species to penetrate deeply into the town, where they find a suitable substrate on bark that becomes secondarily acid as a consequence of air pollution. The increase in hygrophytic species towards the center of Udine is most probably not a consequence of a more humid climate near the town center, but just of the fact that most acidophytic *Parmelietalia*- species are more hygrophytic than the neutro-basiphytic *Xanthorion*-species. In Trieste, on the contrary, these species find their optimal development in the woods surrounding the town. The less poleophobic lichens are in this case *Xanthorion*-species, that are more xerophytic and can stand the drier climate of heavily urbanized areas. *Xanthorion*-species, however, are generally neutro- basiphytic, and in fact the epiphytic vegetation of Trieste in heavily urbanized areas is restricted to the base of the trees (accumulation of dust and nitrates). Summarizing, drought seems to be the main limiting factor for lichen growth in the town of Trieste, whereas in the case of Udine the distribution of lichens seems to be most dependent on acidification of the bark by air pollution. In any case, it is clear that the same explanatory model cannot be applied to the two towns, and that before deciding what hypothesis is «better» one should take into consideration a whole series of edaphical and climatical factors that may have different importance in influencing lichen growth in different towns.

The hypothesis that air pollution is the main factor affecting lichen distribution around the town of Udine is further corroborated by another fact. The distribution of the four lichen zones (fig. 12) is not concentric to the center of the town, being clearly shifted southwestwards. This direction fairly well corresponds with the resultant of the two main winds blowing upon the town of Udine (see fig. 2). It seems therefore that, in contrast with the Trieste case, the town of Udine constitutes a good object for studies on lichens as indicators of air pollution.

RIASSUNTO — Scopo del presente lavoro è analizzare la distribuzione dei licheni epifiti nell'ambito dell'area urbana della città di Udine. Lo studio è basato su 167 rilievi fitosociologici, effettuati su alberi a scorza eutrofica. Tali rilievi sono stati sottoposti a classificazione numerica e ad ordinamento. Quattro gruppi principali di rilievi vengono definiti dalla classificazione numerica. Essi corrispondono alle seguenti unioni di licheni epifiti:

- a) *Physcietum eleaeinae candelariosum* (gruppi 1 e 2, il gruppo 1 rappresenta una facies impoverita).
- 2) Sociazione a *Parmelia* spp. vv. (gruppo 3)
- 3) *Lecanoretum conizaeoidis* (gruppo 4).

I quattro gruppi sono distribuiti in fasce più o meno concentriche rispetto al centro cittadino, nel seguente ordine (dal centro alla periferia): 4,3,1,2. L'ecologia dei gruppi di rilievi è stata studiata utilizzando gli indici ecologici proposti da WIRTH (1980) per le singole specie, e riguardanti la tolleranza a pH, luce, nitrati, aridità. Risulta che dal centro verso la periferia aumentano le specie neutro-basifitiche, xerofitiche, eliofitiche e fotofitiche. Nella discussione si paragonano i risultati con quelli, alquanto diversi, ottenuti per la città di Trieste (NIMIS, 1985) e si conclude affermando che il fattore più importante nel determinare la distribuzione dei licheni nella città di Udine sembra essere l'inquinamento atmosferico.

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