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Angular distribution of epiphytic lichens on *Tilia* trees as a result of car traffic

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M. Del Guasta. **Angular distribution of epiphytic lichens on *Tilia* trees as a result of car traffic.**

A survey of foliose, epiphytic lichens on *Tilia* sp. barks in the rural Mugello valley (Tuscany, Italy) has shown that, in moderately polluted sites, lichen species that find their optimum in *Xanthorion parietinae* replace the species belonging to *Parmelion*, that are common in "clean" sites. By studying the angular distribution of 6 common epiphytic lichens on the barks of *Tilia* trees lining two main Mugello roads, it was possible to demonstrate that *Physcia adscendens, Candelaria concolor, Xanthoria parietina* and *Parmelia subrudecta* are more abundant on the bark facing the vehicular traffic because of the eutrophication induced by the dust and spray lifted by cars. *Parmelia caperata* and *Parmelia tiliacea* are scarce (and often necrotic) in these moderately polluted environments, but do not show any significant preferential distribution on the bark. The results raise some questions about the causes of the modification of epiphytic lichen communities in moderately polluted areas which, too often, are attributed to sulfur dioxide.

Key words: air quality, bioindicators, lichens

Epiphytic lichens are among the most sensitive biological indicators used in the monitoring of air pollution. Modification of the epiphytic lichen vegetation close to strong sources of pollution of known composition, either described by specific maps (for an overview see Ferry, 1973; Deruelle, 1978a) or by syntetic indices, collectively called Indices of Atmospheric Purity (IAP); Deruelle, 1978a; Ammann *et al*., 1987) has been shown to be highly correlated to the concentration of several pollutants. Most studies have dealt with sulfur dioxide, because, historically, it is one of the most important pollutants in industrial and urban areas.

In urban and rural areas, after the fast decline of SO_2 concentrations that has occurred in recent decades (CORINAIR90), the "pollution" sensed by lichens is a more complex cocktail of myco-phytotoxic chemical compounds, nutrients and solid particles, and a direct correlation between a single pollutant and the lichen community is not often found. The studies of Ammann *et al. (*1987), and Liebendoerfer *et al*. (1988) carried out in Swiss towns, showed that IAP values obtained as the sum of the frequencies of all species within a sampling grid of 10 sub-units were strongly correlated to a linear combination of 8 different pollutants. Sulfur dioxide and dust were found to be the most important pollutants in determining the IAP values. Sulfur dioxide has had very high concentrations in past decades, also in small cities: peak SO_2 concentrations above 200-400 $\mu g/m^3$ were usual in urban areas.

Recently, the annual median SO_2 concentrations in Italy have fallen below the legal limit of 80 $\mu g/m^3$ even in the most polluted towns. The same applies for the 98th percentile, which is below 250 $\mu g/m^3$. For this reason, chemical and physical factors other than SO_2 have become increasingly important in affecting the lichen vegetation in areas distant from power plants and heavy industries. To complicate the problem, in slightly polluted areas the effects of pollutants on epiphytic lichens can be masked by community changes due to the local pattern of ecological factors such as humidity, nutrients, and sunlight (LeBlanc & Rao, 1973; Nash, 1996).

Roads crossing rural areas are a peculiar environment in which the sensitivity of lichens to traffic pollution can be tested. Roads in the countryside are a weak source of sulfur dioxide, which is mainly produced by old Diesel vehicles. Several studies carried out along roads and highways have shown the usefulness of lichens as bioaccumulators of the heavy metals challenged by incombuste particles (Nash, 1996), but the lichen community changes induced by traffic have rarely been reported. In their early studies, Barkman, (1958) and Rydzak, (1970) already observed that trees lining the main roads often support lichen communities which are atypical as compared with those of similar trees some distance away from them. Ferry (1973) reported that lichens typical of eutrophic habitats are common along roadside trees affected by manure and dust, and can even disappear if trees are along a road enclosed by edges or walls. However, he did not relate these observations to traffic and suggested that the salt scattered on the roads to melt ice, once sprayed on the trees by passing cars, was responsible for this effects.

For the above reasons, trees lining roads are not used in lichen-mapping studies. But in the urban environment, trees are almost always found along streets, and these trees are normally used for lichen mapping. For this reason, the study of lichen communities on trees lining sealed roads in unpolluted areas may shed some light on the real causes of the decline of lichens in peri-urban and urban areas.

On an average, traffic introduces a micrometeorological wind component in the driving direction. This component, which adds to the larger scale winds, is sensed only in a "channel", several meters in diameter and centered on each lane. In this "channel", turbulence enhances the rising of dust and spray, contributing to the eutrophication of the bark of the roadside trees. In limestone areas such as the Mugello valley, neutro-basiphylic and nitrophilic lichens could be favored on the side of the tree exposed to traffic. Engine exhausts, that diffuse and flow around the trunk after the passage of the car, can contribute to the eutrophycation of bark by the deposition of NOx. Soot and heavy metals are deposited on the bark, challenged by aerosols. In wet weather conditions, the spray produced by the passing of cars is an important source of soil-soluble ions and solids for lichens, with the humid bark acting as a directional trap.

The asymmetrical depositing of pollutants, nutrients, and dust between the exposed and the "protected" side of the tree trunk can induce an asymmetrical distribution of lichen species. This asymmetry is the subject of this study.

MATERIALS AND METHODS

THE STUDY AREA

The Mugello valley is a poorly-industrialised area located 30 km north-east of Florence (I) formed by the Sieve river. The Apennine mountains form the eastern boundary of the valley, while Mt Giovi and Mt Morello (approx. 1000 m in altitude) represent the western boundary (Fig. 1). The rainiest month is October (150 mm rain); the driest month is July (30 mm). The mean of the maximum temperatures in the bottom of the valley has a peak in July (32°C). January is the coldest month (the mean of the minimum temperatures is -2°C). The climate is temperate, classified in the C mesaxeric region (Tomaselli *et al.* 1973). The soil in the study area consists of Riss-Wurm fluvial sediments and recent alluvial sediments. The vegetation is dominated by deciduous trees (*Quercus* sp.). Corn, sunflowers, wheat and forage grass are widely cultivated.

Two main roads have been selected for this study: State Road 503 ("del Giogo"), that crosses the valley, and the Provincial Road 55 ("traversa del Mugello") that connects the main cities along the bottom of the valley (Fig.1). The altitude of the study area is 200 m a.s.l. approximately.

SAMPLING

Two different types of sampling sites were used to assess the effect of pollution on lichen vegetation. All the samplings were carried out in the spring of 1997.

The most common tree along the main roads of Mugello is *Tilia* sp. Most of the lime-trees actually bordering the Mugello roads are almost coeval, about 30-40 years old. Trees selected for this study lined the roads (less than 1.5 m from the road edge), had a diameter of at least 30 cm, and bore no signs of car crashes or other damage.

Two types of sampling stations were selected. The type "A" sampling sites were represented by 8 sites (in Roman numerals, Fig.1). These stations were used to overview the local lichen vegetation and to define the commonest and most conspicuous foliose lichen species to be used in the rest of the work, followig the so called "Swiss method". The type A stations covered a wide range of air-quality situations: from clean, rural areas to urban areas. Site I was a reference, unpolluted station where car traffic is completely absent. This site was an abandoned, unsealed road bordered by lime-trees for about 600 m. The road had been abandoned about 40 years ago (at that time, a new road was built about 500 m away), and actually crosses a corn field.

Site II, close to a small hospital, showed a low car traffic of a few dozen cars/day. Site III was close to the city of Borgo S. Lorenzo (about 15000 inhabitants), but was located in a relatively protected place, close to the Sieve river, where car traffic is limited. Sites IV and V were located along two main roads, with a car traffic of 10 cars/minute or more. Sites VI was located along the busiest street of the city of S. Piero a Sieve (about 5000 inhabitants). Pollution is determined by car exhausts, domestic heating, and limestone dust carried by trucks serving a local limestone quarry. Site VII was located in the suburbs of S. Piero a Sieve, on a very dusty road leading to a gravel excavation. Site VIII was located along the main road of Borgo S. Lorenzo, close to street lights. It is a polluted site, due to car exhausts.

For each type "A" station, a careful analysis of foliose lichen vegetation was carried out on a minimum number of 10 trees. A few easily-identified crostose lichens (*Lecanora* gr *chlarotera, Candelariella xanthostigma, Lepraria incana)* have also been considered. For the identification, the keys of Nimis (1987) were used, with the help of the photographic atlas of Jahns, (1992). For the lichen nomenclature, Nimis (1999) was followed. The ecological preferencies of the species were obtained from Wirth (1980) and Nimis (1999). A total of 25 lichen species were considered for this preliminary vegetation study. A sampling grid (30 X 70 cm), subdivided into ten rectangles, similar to those used by Liebendoerfer *et al.* (1987) and Nimis *et al.* (1991), was placed on the bark at 1.5-

1.7 m above the ground on the trunk side which showed the maximum variety of lichens. The sampling strategy is the same as that used for the evaluation of IAP (Index of Air Purity) with the method suggested by Amman *et al.* (1987): the specific frequency of each of the 25 selected lichens was measured on each tree by counting the number of grid-rectangles containing visible talli of the species. The IAP index, which is defined as the sum of the specific frequencies, was computed for each tree. A "mean" IAP for each type A site was computed, together with its S.D. and the histogram of IAP values.

Type "B" sites were represented by 8 sampling sites, including 1 reference site (Fig. 1). Reference site 4 was located in the same place as the type A site I, with no traffic. The other 7 sites were chosen along the main roads with medium/heavy traffic (10 cars/minute or more). All sites of type "B" were composed of two equal groups of at least 5 trees each: one group for each side of the road.

All trees on the 8 sites faced car traffic on one side only; the other side faced the countryside or other traffic-free areas.

Six lichen species were selected from the results of the analysis of the type "A" sites: the species were chosen from among the most abundant species observed in the clean and moderately polluted sites of type A. If abundant, the 6 species selected, (*Parmelia caperata, Parmelia .tiliacea, Parmelia subrudecta, Physcia adscendens, Candelaria concolor, Xanthoria parietina),* are also clearly visible on the bark from some distance.

Every tree was studied at a height of 1.5-1.7 m above the ground (a change in lichen vegetation occurred on most trees at about 3-4 m from the ground, with a typical increase of *Parmelion* species in the upward direction). Each selected trunk was ideally divided into 8 angular sectors of 45° each, with the help of an elastic rope with 8 knots surrounding the trunk. The direction of the lane closest to the tree was used as a reference for numbering the sectors clockwise. The "zero" direction pointed at incoming traffic.

The presence in each sector of each of the 6 selected species was recorded as a presence/absence index: 1 if the species was present and visually conspicuous, 0 if the species was absent or present with a few talli. This technique obviously has a certain degree of subjectivity, but the selected species had unmistakable colors that were easy to detect on the trunks. The threshold between presence and absence was given by the continuity /absence of continuity of the specific color pattern.

For each lichen species, all the angular distributions produced in all sites except "clean" site 4, for a total of 116 trees, were added up. The final distribution obtained for each lichen species (Fig. 2) has its "zero degree" angle toward the incoming traffic, 90 degree direction perpendicular to the road, and 270 degree direction facing the countryside. If the traffic had a direct effect on the lichen vegetation, a preferential, directional distribution of some lichen species should have been visible in the final distribution. If the angular distributions on each tree were caused by autoecological factors, no preferential direction would have arisen from this type of analysis; the effect of prevailing winds is also cancelled. The final angular distributions for the 6 selected lichen species were tested with the Rayleigh test, to check the statistical validity of the mean directions obtained (Batschelet, 1981). The analysis was carried out separately for the "clean" site 4 (Tab IIa) and for the "polluted" sites (Tab. IIb).

RESULTS AND DISCUSSION

The results from the survey of type A sites (Tab. I) showed that the IAP index ranged from 20 (±7.5) in the most polluted urban site VIII to 54 (±12) in "cleaner" sites. Vegetation was dominated by acido-hygrophylic species belonging to *Parmelion* in the cleanest site I, with a widespread presence of *Parmelia caperata, Parmelia tiliacea,* and *Parmelia subrudecta.* The gradual colonization of neutro-basiphytic, xerophytic species, which find their optimum in the *Xanthorion parietinae* vegetation, was evident as soon as traffic reached low levels (sites II, III), with the increasing presence of *Physcia adscendens, Xanthoria parietina, Candelaria concolor, Hyperphyscia adglutinata, Candelariella xanthostigma.* In the busier roads (sites IV, V, VI), the *Xanthorion parietinae* became dominant, with a strong depletion of *Parmelion* species, that often showed necrotic signs. In the most polluted sites (sites VII, VIII), *Physcia adscendens, Hyperphyscia adglutinata,* and *Physconia grisea* were the most abundant species. A similar community change, moving from the suburbs of Trieste to downtown, was observed by Nimis (1985), and by Nimis *et al.* (1991) in a survey of Veneto (northern Italy) lichens.

It must be stressed that, in the present study, IAP values did not change significantly going from "clean" to moderately polluted sites, and remained in the 45-54 range. IAP were thus insensitive to the shift from *Parmelion* to *Xanthorion parietinae.* A slight IAP increase in moderately polluted sites (IV, V, VI) with respect to "clean" sites (I, II, III) was observed instead, as a result of the co-presence of *Parmelion* and *Xanthorion parietinae* species. IAP decreased down to 20-30 only in sites VII and VIII, which were located in urban areas.

A gradual shift from *Parmelion* to *Xanthorion parietinae* vegetation was observed on *Quercus cerris* along an unsealed road leading to a limestone cave in the Mugello valley by (Del Guasta, 1994). In that case the effect was closely related to the calcareous dust induced by the passage of the quarry trucks, and was explained with the neutralization of the bark, leading to the colonization of neutro-basiphylic *Xanthorion parietinae* species.

In the present study, the shift from *Parmelion* to *Xanthorion parietinae* vegetation was detected along sealed roads with much less dust. As a first hypothesis, a direct contribution to this community shift coming from the agricultural activities could not be excluded. Dust from the surrounding fields could bring soil and nutrients to the tree bark, leading to bark eutrophication. In fact, the presence of *Xanthorion parietinae* species on *Tilia* barks was associated by Nimis *et al.* (1991) with the eutrophication of the bark due to agricultural activities.

Results from the type B sites (Tab. IIa) showed a marked and significant preference of *Physcia adscendens, Xanthoria parietina, Candelaria concolor*, and *Parmelia subrudecta* for the side of the trunk facing traffic. Most of these species prefer illuminated environments (Tab. I), and thus their abundance in the *Tilia* sectors watching the road cannot be explained with a different illumination, since the ligth irradiance above a tree-lined road is (at least in spring-summer) lower than in the surrounding environment.

The results agree with the preference of *Physcia adscendens, Xanthoria parietina, Candelaria concolor* for eutrophicated and neutro-basic environments. The same result was obtained for *Parmelia subrudecta,* a species that is ecologically intermediate between *Xanthorion* and *Parmelion* vegetation (Nimis, 1999). This specie resulted present (sometimes abundant) in the polluted type-A sites VI, VII, and VIII, showing that this species has followed the fate of the other three *Xanthorion parietinae* species *Physcia adscendens, Xanthoria parietina, Candelaria concolor.*

Parmelia caperata and *Parmelia tiliacea* were scarce in type-B sites 2-8, and their distribution on the tree trunks was statistically "unpolarized".

In the type-B, reference site 4, *Xanthorion parietinae* vegetation was almost absent, and all the 6 species selected in this study did not show any preferential direction with respect to the (hypothetical) driving direction along the abandoned road (Tab. IIb and Fig. 3). The distribution of *Parmelia caperata* and *Parmelia tiliacea* in the reference site reflected the "autoecology" of the two species, that showed a preference for the northern part of the trunks, perhaps because of the shading that they receive during the dry summer months.

CONCLUSIONS

The preference of three neutro-basicophytic, nitrophytic *Xanthorion parietinae* species (*Physcia adscendens, Xanthoria parietina, Candelaria concolor),* and *Parmelia subrudecta* for the *Tilia* sectors exposed to traffic seems not to be related to SO_2, because the concentration of sulfur is actually very low in petrol and Diesel fuels (CORINAIR90). Very likely, during their (turbolent) diffusion from the source to the tree, exhaust gases do not show the sharp horizontal gradient required to explain a very different SO_2 / NO_x concentration between the two sides of the trunk (even if a wet bark facing the traffic could have a higher efficiency of gas solubilization than the "hidden" one).

The lichen distributions observed in this study were incompatible with a direct bark eutrophication caused by agriculture: site 4 (reference) and site 6 (on the road) were very close each other, embedded in the same, agricultural environment, but nevertheless showed markedly different lichen vegetation. More probably, dust (of rural origin) and sprays produced by the passage of cars caused the asymmetrical lichen distributions observed. The capture-efficiency for coarse aerosols is very likely higher on the trunk side-that is invested by the "cloud" of particles moving together with the car-than on the shaded trunk. Dust and sprays contribute to the bark eutrophication, and bring heavy metals, soot, and limestone that neutralizes the bark acidity. This mechanism, in which solid and liquid aerosols are apparently more important than pollutant gases in modifying the epiphytic vegetation along the roads, could represent the major impact of human activities on lichens in moderately polluted areas.

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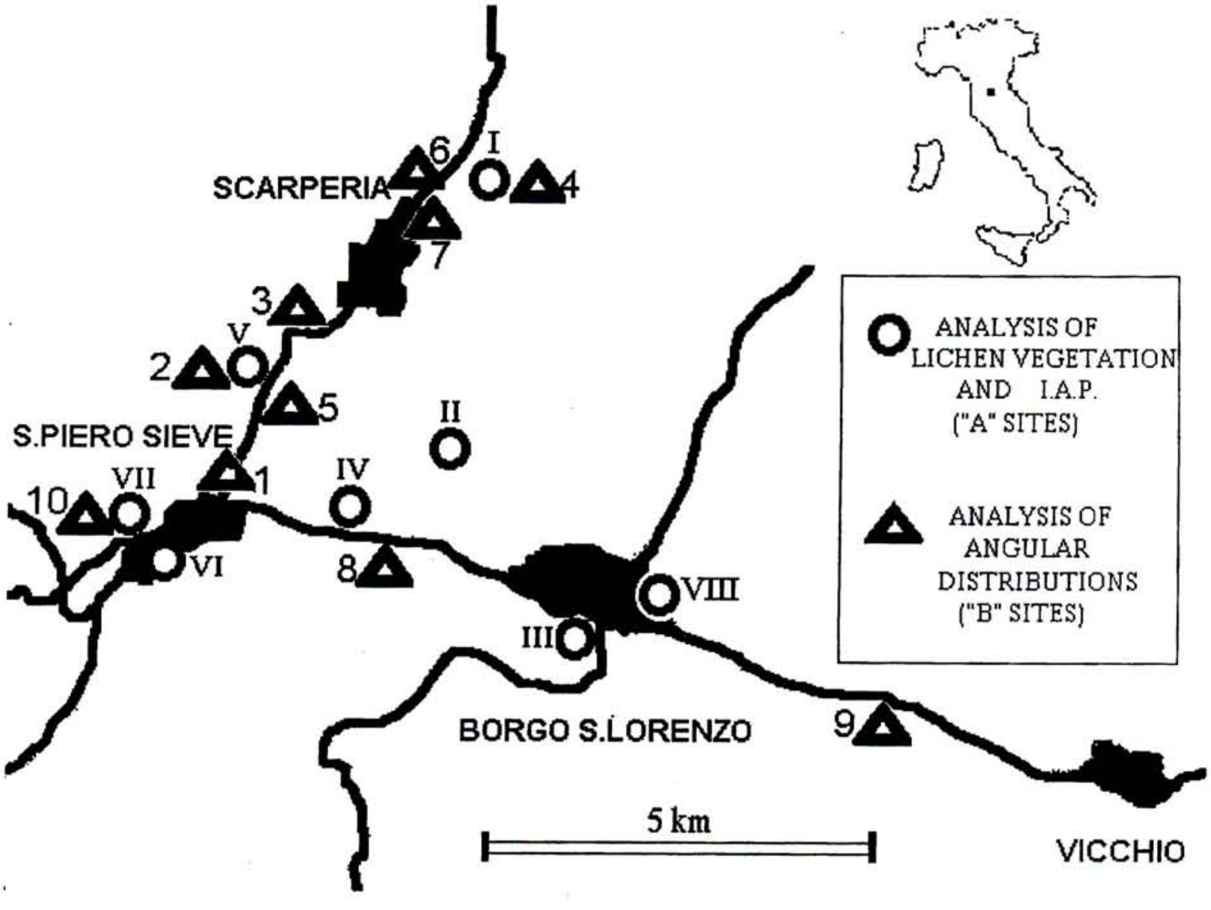

Fig. 1 - Map of the area showing the main roads (black lines) and cities (black spots). Type A and B sampling sites are shown (see text).

LICHEN SPECIES	SITE I	II	III	IV	V	VI	VII	VIII	Eutr. Index	Ligth Index
Parmelia caperata (L.) Ach.	6.6	7.8	7.9	2 .4	4.1	2.7	0.7	0	1-2	4
Parmelia tiliacea (Hoffm.) Ach.	9.6	2.2	3.5	3.6	4.1	5.8	0.4	1.6	2-3	3-4
Parmelia subaurifera Nyl.	0.3	4.5	0.2	0.1	0.5	0.2	0.1	0	1-2-3	3
Parmelia sulcata Taylor	1.3	4.2	2.2	1	0.9	0.1	0.7	0	1-2-3	3-4-5
Parmotrema chinense (Obseck) Hale and Ahti	0.1	0	0.1	0.2	0.1	0	0	0	1-2	3-4
Parmelia subrudecta Nyl.	7.2	5.5	6.4	5.4	4.3	8.5	2.5	1.4	1-2-3	3-4
Parmelia acetabulum (Neck.) Duby	0.7	0	0	0.1	0.2	0	0.2	0	2-3	4-5
Xanthoria parietina (L.) Th.Fr.	0.1	0.2	2.2	3	2.7	3.1	0.9	0	3-4	4-5
Ramalina sp.	0.2	0.2	0.5	0.1	0	0.2	0	0		
Hyperphyscia adglutinata (Florke)	0	1	5.3	0	0	6.6	4.8	0	3-4-5	4-5
Physcia adscendens (Fr.) H.Oliver	1.8	9	8.6	8.7	8.9	8	6.8	6.6	3-4-5	4-5
Phaeophyscia hirsuta (Mereschk.) Essl.	0.5	0	0.1	2.8	1.9	5.1	3.2	0	3-4	4-5
Physcia biziana (A.Massal.) Zahlbr.v.biziana	0.2	2.3	0	0	0 .7	0.5	0	0	3-4	4-5
Physcia orbicularis (Neck.) Moberg	0	0	0.6	0	0	0.2	0	0	4-5	3-4-5
Physconia grisea (Lam.) Poelt ssp. grisea	2.9	0	2	1.1	4.5	8.6	4	10		
Physconia venusta (Ach.) Poelt	2.8	0.2	0	0.2	0.9	0.3	0	0		
Physconia distorta (With.) J.R.Laundon	2.6	0	0.1	0.3	0.3	0	0	0		
Lecanora gr. chlarotera	0	0	0	3.8	0.7	1	4.5	0		
Candelaria concolor (Dicks.) Stein	2.4	9.5	9.5	10	9.9	2.3	0.2	0		
Candelariella xanthostigma (Ach.) Lettau	2.3	2.2	4.2	0	5.1	0.3	1.4	0		
Diploicia canescens	0.1	0	0	2	0	0	0	0		
Pertusaria pertusa (Weigel) Tuck.	1.5	0	0	0.2	0	0	0.2	0		
Lepraria incana	0.9	0.3	0	0	0.1	0	0.7	0		
Physcia aipolia (Humb.) Furnrh.	2.2	0	0	0	0	0.2	0	0	3-4	4-5
Number of Trees	25	6	10	9	15	10	11	5		
mean I.A.P.	46	49	53	45	50	54	31	20		
I.A.P. Standard deviation	12	11	9	11	7	15	15	7.5		
Car Traffic level	absent	low	low	medium	medium	high	high	high		
Short Site description	old road	Hospital	city garden	main road	main road	city (dusty)	city	city		

Tab. I - Type "A" sites: overview of the local lichen vegetation on *Tilia* trees. Mean specific frequencies aere reported for each site. Specific frequencies above 5 are underlined. Traffic level is roughly considered "low" with a few cars/hour, "high" with urban-main road levels (>10 cars/minute). When available, the ecological indices for eutrophication and for ligth exposition (Nimis, 1999) are reported.

TYPE B SAMPLING SITES

LICHENS ON "POLLUTED" TREES (SITES 1,2,3,5,6,7,8, total 116 trees)

ANGULAR SECTOR	1	2	3	4	5	6	7	8	MEAN DIRECTION	r	z	Rayleigh Test
Xanthoria parietina	24	25	12	5	3	2	5	9	49.5	0.54	25.1	p<0.0005
Parmelia subrudecta	12	21	20	18	11	10	6	6	112	0.3	9.28	p<0.0005
Physcia adscendens	34	34	26	18	9	10	15	15	59.6	0.32	16.3	p<0.0005
Candelaria concolor	21	23	18	17	6	2	4	12	73.4	0.42	17.8	p<0.0005
Parmelia tiliacea	9	10	11	11	9	7	8	6	122	0.13	1.14	unsignificant
Parmelia caperata	8	7	8	9	9	11	6	5	186	0.11	0.81	unsignificant

Tab. IIa - Directional distribution of 6 lichen species on (type B) sites. The reference direction (0 deg.) is directed toward the trafic flow. "r" is the mean vector length. Data are considered unsignificant if p>0.1

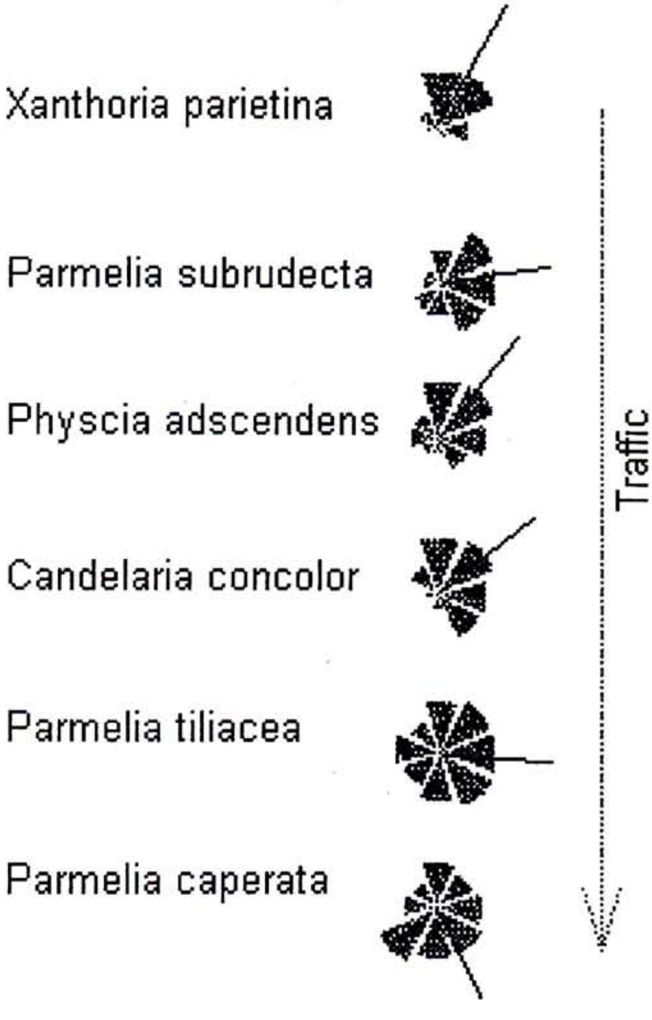

Fig. 2 - Cumulative angular distribution (arbitrary units) of the 6 selected lichen species in the 116 trees studied in type B sites. In these plots, the road lane closer to the tree runs along the right side of each plot, with traffic running from

TYPE B REFERENCE SITE

LICHENS ON REFERENCE TREES (SITE 4, total 12 trees)

ANGULAR SECTOR	1	2	3	4	5	6	7	8	MEAN DIRECTION	r	z	Rayleigh Test
Xanthoria parietina	0	0	0	0	0	0	0	0				
Parmelia subrudecta	0	0	0	0	0	0	0	0				
Physcia adscendens	2	1	2	1	1	0	1	1	28	0.28	0.68	unsignificant
Candelaria concolor	0	0	0	0	0	0	0	0				
Parmelia tiliacea	5	2	5	8	7	2	4	6	11	0.11	0.47	unsignificant
Parmelia caperata	4	4	5	4	4	0	2	3	27	0.27	1.91	unsignificant

Tab. IIb - Directional distribution of 6 lichen species on (type B) reference site 4. The reference direction (0 deg.) is directed towards the (absent) trafic flow. "r" is the mean vector length. Data are considered unsignificant if p>0.1

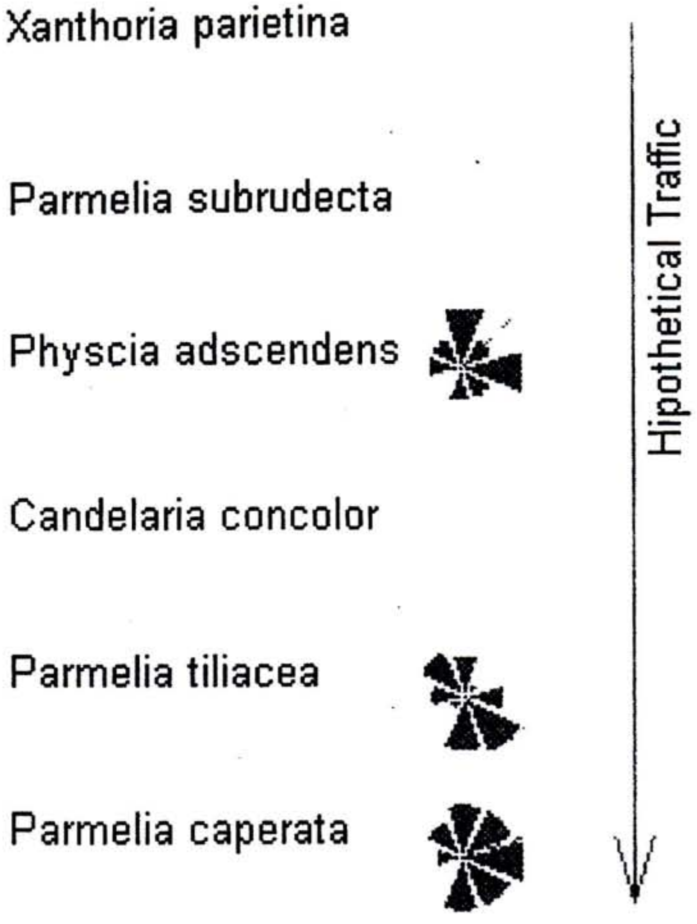

Fig. 3 - Cumulative angular distribution (arbitrary units) of the 6 selected lichen species in the reference type B site 4. In these plots, the road lane closer to the tree runs along the right side of each plot, with (hypothetical) traffic running