Possibilities and Methods for Mapping Air Pollution on the Basis of Lichen Sensitivity

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ABSTRACT

For various reasons lichens seem to be much more sensitive to air pollution than flowering plants. Various methods to map the long-range effect of phytotoxicants on epiphytic lichens and mosses have been proposed. This paper outlines a few of these and proposes a new method. In Sudbury, Ontario, vegetation has been greatly affected by sulfur dioxide emanating from three huge smelters. The author shows that his map based on the response of lichens matches quite well with another map from the same area based on continuous SO_2 monitoring. The advantage of the biological map is that it took two weeks to accumulate the data required while the other one took ten years.

BIOLOGICAL METHODS FOR MAPPING ATMOSPHERIC POLLUTION

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It is a well-known fact that lichens are, in general, more sensitive to air pollution than any other group of plants. Some of the reasons for this are: a) the limited quantity of chlorophyll of their thallus and hence their low net productivity which certainly reduces their potential for recovery or recuperation after fumigation; b) their enormous (and non-selective) potential for accumulating substances from the atmosphere in which they are growing, for lichens are dependent on rainfall and ambient air for nutrients; c) their perennial evergreen habit; d) the exposure of corticolous species, which lack a protective snow blanquet, to the high pollution levels prevalent during winter.

It is easy to observe that as one approaches large conurbations or industrial complexes, epiphytic lichens and mosses gradually decrease in vitality, in coverage and in frequency, leaving in the center of these areas a large epiphytic desert where no lichens or mosses are found.

Over the years pollution has caused fantastic damages to plants over large areas in Europe. For example, according to Barkman (1969), within the last century the Dutch flora has lost 3.8% of its flowering plant species, 15% of its terrestrial bryophyte species, 13% of its epiphytic bryophyte species and 27% of its epiphytic lichen species.

The use of lichens and mosses as indicator species in pollution studies has been, for the past decade, greatly emphasized in Europe. Barkman (1958), Skye (1968), DeSloover and LeBlanc (1968) have reviewed most of the pertinent literature.

One of the aspects developed by many authors has been the use of maps to illustrate the extent of damage to lichens and mosses by pollution. The presentation of data in the form of a map is certainly a refined method to summarize information gathered from the field. Many types of maps have been published and it is not my intention to present a catalogue of them all. Here are, however, a few samples.

I. Species distributive maps

This type of map simply illustrates by means of symbols the presence or absence of a species growing in or around a large conurbation, in the neighborhood of an industrial complex, or even over a larger territory such as a state or a province. Sometimes quantitative (coverage, frequency, etc.) or qualitative (vitality, periodicity, etc.) factors are estimated. On the basis of this information the territory investigated is usually divided into zones which are correlated with such factors as pollution, urbanization, industrialization, etc. This method was adopted by Beschel (1958), Skye (1958), Barkman (1963), LeBlanc and DeSloover (1970), etc., in their respective studies of Innsbruck and Salzburg (Austria), Kvarntorp (Sweden), Province of Limburg (Belgium), and metropolitan Montreal (Canada). It is relatively easy and rapid to collect the basic data for mapping if one considers only the distribution of a single species. This kind of work can be done by any technician or even a high school student if an easily recognizable species is selected.

In order to render more accessible to non-lichenologists the information provided by epiphytic lichens, Skye (1958) suggested that only a few easily recognizable indicator species should be selected. He proposed such species as: Anaptychia ciliaris, Evernia prunastri, Parmelia acetabulum, Ramalina fraxinea, Xanthoria parietina. DeSloover and LeBlanc (1968) recognized this method as interesting but thought that it "opened the door to an impoverishment of the information desired". After further study of this question, this author now withdraws his previous statement and thinks that Skye's ideas on species distributive maps are both sound and practical.

The information gathered from species distributive maps is almost as complete and informative as that obtained by more elaborate and sophisticated methods. In another section of this paper I will try to show how the information gathered from species distributive maps compare with that obtained by other methods.

II. Vegetative maps

Many authors have studied in great detail the entire epiphytic vegetation of a city or of a larger area around an industrial complex. This involves ecological or phytosociological investigations. Usually the data gathered is summarized and maps are drawn often delineating generalized zones: a) an innermost zone which covers the more densely populated parts of a city where the epiphytic vegetation is absent or scarce (the "epiphyte desert"); b) an outermost zone where corticolous epiphytes become abundant and well developed because of clean air and other favourable ecological conditions; c) an intermediate zone, or "struggle zone" (Kampfzone), sometimes divided into narrower subzones, where the epiphytic vegetation ranges from poorly developed to nearly normal.

a) Small scale vegetative maps

Few generalized small scale vegetative maps have been published. Hawksworth and Rose (1970) prepared a map estimating qualitatively the extent of air pollution in England and Wales by using lichens growing on trees. Rao and LeBlanc (1967) published a map of an area in the boreal forest near Wawa, Ontario, where the climax vegetation had been destroyed by sulphur dioxide emanating from an iron-sintering plant (Fig. 1). The latter map is based on the number of epiphytes and the concentration of sulphate in the soil and correlates well with a map prepared by Gordon and Gorham (1963) based on a study of the flowering plants and aerial photographs. Barkman (1958) after many years of study of the vegetation of the Netherlands produced a generalized map of that country showing enormous areas around large conurbations and important industrial centers where epiphyte deserts appear very prominent.

b) Medium scale vegetative maps

Among the medium scale vegetative maps let me cite the following: Gilbert (1969) published an interesting map of the Lower Tyne Valley in England where he shows the limit of the lichen desert on ash tree, on sandstone, and on asbestos. Domrös (1966) prepared a map of the middle part of the Rhine-Westphalian industrial region based on the coverage of the lichen vegetation on trees. DeSloover and LeBlanc (1968) prepared a map of an area in the Dendre Valley, NW Belgium, according to the I.A.P. method (to be explained later) and taking into consideration the entire lichen and bryophyte vegetation of that region.

c) Large scale vegetative maps

Large scale vegetative maps have been published by several authors who synthesized their data and presented generalized sketches showing belts of epiphytic vegetation around urban areas or industrial complexes (Fig. 2). A few of the cities mapped are: Oslo (Haugsjå 1930), Stockholm (Hoeg 1936), Helsinki (Vaarna 1934), Zürich (Vareschi 1936), Debrecen (Felföldy 1942), Uppsala (Krusenstjerna 1945), Vienna (Sauberer 1951), Caracas (Vareschi 1953), Bonn (Steiner and Schulze-Horn 1955), München

(Schmid 1957), Montreal (LeBlanc 1961), Rudnany (Pisut 1962), Stockholm (Skye 1964).

d) Barkman's map of the Limburg Province

Recently more refined medium scale vegetative maps have been published. Barkman (1963) prepared a map of the Limburg Province in NE Belgium based solely on the total number of species present in the 159 localities investigated and covering an area of approximately 1000 sq km. This map shows clearly that the poorest epiphytic flora is found around mines and factories and the richest in old mixed deciduous woods and parks especially in valleys. To prepare this type of map one must be somewhat of a taxonomist otherwise many species will remain uncatalogued. This type of map, evidently, gives more information on the influence of pollution and industrialization than all the preceeding ones. It takes much time and energy, however, to gather the necessary data, and if one is to go through the trouble of indentifying all the species present at a great number of stations one might just as well gather also phytosociological information and prepare more complete and informative maps such as the following two described below.

A very striking and unusual cartographic document, again by Barkman (1963), and for the same region at the same scale as the preceding one is based on the assumption that phytosociological associations give a better indication of the influence of air pollution than sheer numbers of species.

Proof of the validity of this assumption depends on development of a scheme to reduce to a minimum the number of association-groups presented on a map. Unfortunately, this is only partly the case for Barkman's beautiful mosaic color map where the various contour patterns are so complicated to follow that I doubt the practicability of such maps to express in an easily readable form the long range effects of air pollution on vegetation. Here again it is not easy to prepare this type of map for one must be, not only a taxonomist, but also a phytosociologist. However, such maps are undoubtedly interesting to phytosociologists who may be able to visualize at a glance the spatial distribution of epiphytic associations.

e) The I.A.P. method

This is a recently proposed method to map the long range effect of air pollution on epiphytes. The philosophy underlying the method was described by DeSloover and LeBlanc (1968) and a practical application, to wit, metropolitan Montreal, was given by LeBlanc and DeSloover (1970). It is not my intention to describe in detail the method; those interested can consult the two papers cited above. Nevertheless, a short summary will be helpful.

The area to be mapped must be as homogeneous as possible and the choice of "stations" to be studied should be ecologically homologous. Only one species of tree should be investigated if possible and certainly no more than 2 or 3. If more than one species is used, they should have similar physical and chemical bark properties. One must not compare the epiphyte vegetation of a conifer for example with that of a deciduous tree. As many stations should be investigated as time warrants.

All the species of epiphytes present at a station should be listed and their coverage and frequency estimated. With this data one can calculate the I.A.P. (Index of Atmospheric Purity), and the higher the index the purer the air should be. The index for a station is found by the following formula:

$$\text{I.A.P.} = \frac{1}{n}\sum (Q \times f)/10 \quad \text{where}$$

n is the number of epiphyte species,

f is a frequency-coverage scale to be chosen by the investigator,

Q is the degree of resistivity (formerly called "ecological index) of each species to pollution.

It is determined by adding together the number of epiphyte species escorting a particular species (i.e. Parmelia sulcata) at a station and then taking the average of the sums for all the stations where that species was present. The sum of Q x f is divided by 10 to provide small manageable figures.

The I.A.P. from all the stations are then plotted on a map and all those stations having an index within a pre-selected range are linked together by isopleths which will bring out, in a visual form the isotoxic zones.

This type of map, like the preceding one, must be prepared by specialists. The mapped data obtained correlates more vividly than any other type with pollution, urbanization and industrialization.

In Sudbury, Ontario, the ground level concentration of sulphur dioxide over a 4000 sq mi. territory is monitored by ten Thomas automatic recorders for six months each year. Dreisinger (1965) has compiled the data so accumulated over a 10-year period in a map. LeBlanc et al. (1971) have also mapped the same territory using the I.A.P. method. The two maps, although not identical, give approximately the same results. One can point out here that the former and presumably more precise map required ten years to prepare while the latter "biological map" was made in less than one month.

f) Comparison between the I.A.P. and other methods

The data used to prepare our I.A.P. map for Montreal was fed into a computer at Harvard University[1] and the symap computer mapping technique was employed to produce all sorts of maps which would have been almost impossible to conceptualize by conventional methods.

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[1] This work was done by Dr. Jean-Maurice Granger now at Faculté d'Urbanisme, Université de Montréal. I wish to thank Dr. Granger for allowing me to select and reproduce sections from a mimeographed report: "Computer mapping as an aid to air pollution studies. Vol II: Individual reports. Report E: Montreal region study. 29 pages 1970. Harvard University.

Regression analysis was used to determine how much of the variation of one variable - often the I.A.P. - is attributable to another variable or variables - such as the number of epiphytes. One of the measures produced by regression analysis - R^2 - was used frequently. R^2 is given in percent and is an indicator of the degree of information retained. For example, an R^2 of 97% means that the data reduction resulted in a loss of 3% of the information contained in the original data.

The first test performed by Dr. Granger was to see if a land use intensity index (8 categories) and the I.A.P. (Fig. 3) were significantly related. The analysis resulted in an R^2 of 80%, a significantly high value. The land use intensity index wax based on the nature of the land use (industrial, residential or vacant) and the distance from the city center (0-5, 5-10, and 10 + mile radii) for each of the 349 stations investigated by us in metropolitan Montreal.

1. The I.A.P. and the total number of epiphytes.

Another test was performed to see to what degree the number of epiphytes present at each station (Fig. 4) could be compared with the I.A.P. For the entire region (349 values), the R^2 was found to be 97% and the multiple, R, 0.99. This regression shows that 97% of the variation in the total I.A.P. can be explained by the variation in single number of epiphytes present at each station. Thus we see that very little information is lost by using only the epiphyte counts to measure pollution instead of the more complex and therefore more expensive I.A.P.

The land-use intensity index and the number of epiphytes per station were also correlated. The resulting R^2 was 87%. Even though the relationship of the I.A.P. to the number of epiphytes produce a relation ten percent stronger than that of the land-use index and the number of epiphytes, this difference does not appear to be significant, due to imprecisions in land-use measurements.

Two regression analyses were performed to test the number of epiphytes against the I.A.P., separately for the rural (boundary line approximately 10 miles from the city center) and the urban areas. The results were: urban area (142 values): R^2 = 96% (multiple R of 0.98); rural area (207 values): R^2 = 98% (multiple R of 0.99). The difference of 2% between the two is not significant.

2. The I.A.P. vs a few "indicator" species.

If instead of counting <u>all</u> the species present at a station one choses a few "indicator" species and compares them with the I.A.P., little information is lost. Taking into consideration absence or presence, coverage (scale 1 to 5), and fertility for the entire area and all data points (349), a selection of four species (Physcia millegrana, Physcia stellaris, Xanthoria fallax and Leskea polycarpa) (Fig. 5) had an R^2 of 95.5% (for a multiple R of 0.977). An additional four species (Parmelia subaurifera, Candelaria concolor, Parmelia sulcata and Lecanora subfuscata) yielded an R^2 of 97.1% for a multiple R of 0.985). When rural and urban zones were considered separately, the results were:

rural: 8 species - R^2 = 97.5 for a multiple R of 0.988
4 species - R^2 = 96.1% for a multiple R of 0.980

urban: 8 species - R^2 = 95.4% for a multiple R of 0.977
4 species - R^2 = 90.9% for a multiple R of 0.954

If the presence or absence, coverage and fertility of only one species, e.g. Physcia millegrana (Fig. 6) is tested against the I.A.P., the explanatory power of this variable exhibits an R^2 of 89.4%.

An alternate selection of four species of epiphytes (Physcia millegrana, Physcia adscendens, Parmelia subaurifera and Xanthoria fallax), then an additional four species (Leskea polycarpa, Candelaria concolor, Lecanora subfuscata and Parmelia sulcata) were added to the first four and these two sets were compared with the I.A.P. Here presence or absence and coverage only were taken into consideration. This alternate selection gave an R^2 of 94.6% (for a multiple R of 0.974) for four species and an R^2 of 97.1% (multiple R of 0.985) for eight species. The results are almost the same as in the previous test. When the area was divided into urban and rural zones the results were:

rural: 8 species - R^2 = 97.4% for a multiple R of 0.987
4 species - R^2 = 95.7% for a multiple R of 0.987

urban: 8 species - R^2 = 94.6% for a multiple R of 0.973

4 species - R^2 = 91.4% for a multiple R of 0.956

These results are close to those found for the first selection and prove that addition of the fertility data does not add much to our knowledge.

If the presence or absence and coverage of only one species (Physcia millegrana) is tested against the I.A.P. the explanatory power of this variable exhibits an R^2 of 88.4%. Addition of the fertility factor resulted, as seen before, in an R^2 of 89.4%.

CONCLUSION

Possibilities of mapping atmospheric pollution by using epiphytic mosses and lichens should be looked into seriously by foresters. All the methods described here have their advantages and disadvantages. If a cryptogamist is going to do the job, certainly the methods proposed by Barkman or by DeSloover and LeBlanc are the best ones. However, in most cases the more simplified methods will be used.

Given the relative simplicity of directly observing and recording only the identity and the coverage of four epiphyte species - and the high explanatory power still retained - the mapping technique becomes easy because anyone can familiarize himself with preselected species. The problem though will always be the choice of indicator species, a choice which should not prove too difficult for a forester since it must include species of wide distribution.

The method of expressing air pollution degrees, as reflected by the epiphytic vegetation, by means of a simple cartographic document does not give any information on the origin, fluctuations, or causes of pollution. Its principal advantage is that it allows us to visualize qualitatively and at a glance the average condition of air pollution and its effects on epiphytes which are very sensitive plants.

The authors of the maps discussed in this paper do not pretend that their maps express quantitatively pollution problems and it is beyond the scope of this paper to discuss the quantitative aspects. Nevertheless, I cannot refrain from citing here two papers recently published in England which open an entirely new vista on the use of epiphytes as monitor of air pollution and have perhaps great applications for forestry. The first of them (Gilbert 1969) proposes a "biological scale" to deduce roughly the annual average levels of sulphur dioxide present in the atmosphere and the second (Hawksworth and Rose 1970) suggests a ten-point scale using lichens living on trees to provide a method to determine the mean winter values of SO_2 without having to rely solely on elaborate instrumentations. These scales will be particularly useful in localities away from established recording stations which, for practical reasons, are usually restricted to urban and industrial areas. Future research along those lines will be most useful and rewarding.

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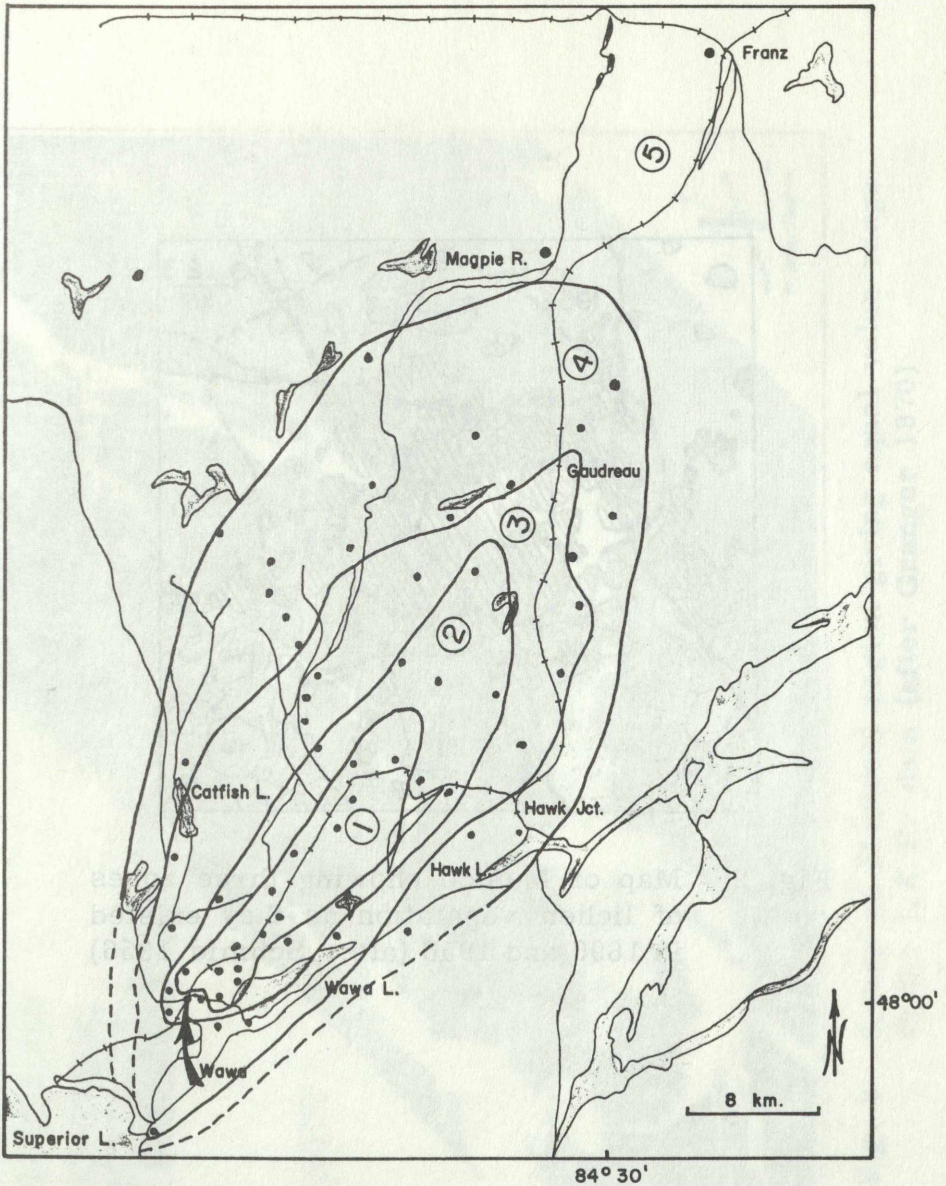

Fig. 1 Approximate boundaries of pollution zones in the Wawa area as established by the number of epiphytic species and the concentration of soil sulphate (after Rao and LeBlanc 1967)

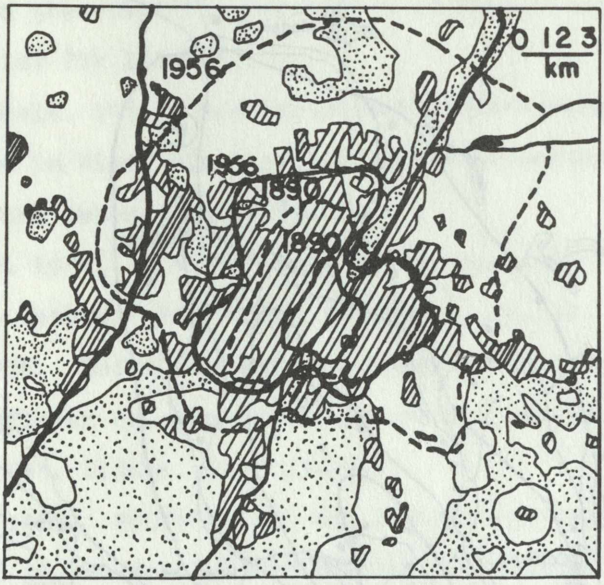

Fig. 2 Map of Munich showing three zones of lichen vegetation as they existed in 1890 and 1956 (after Schmid 1956)

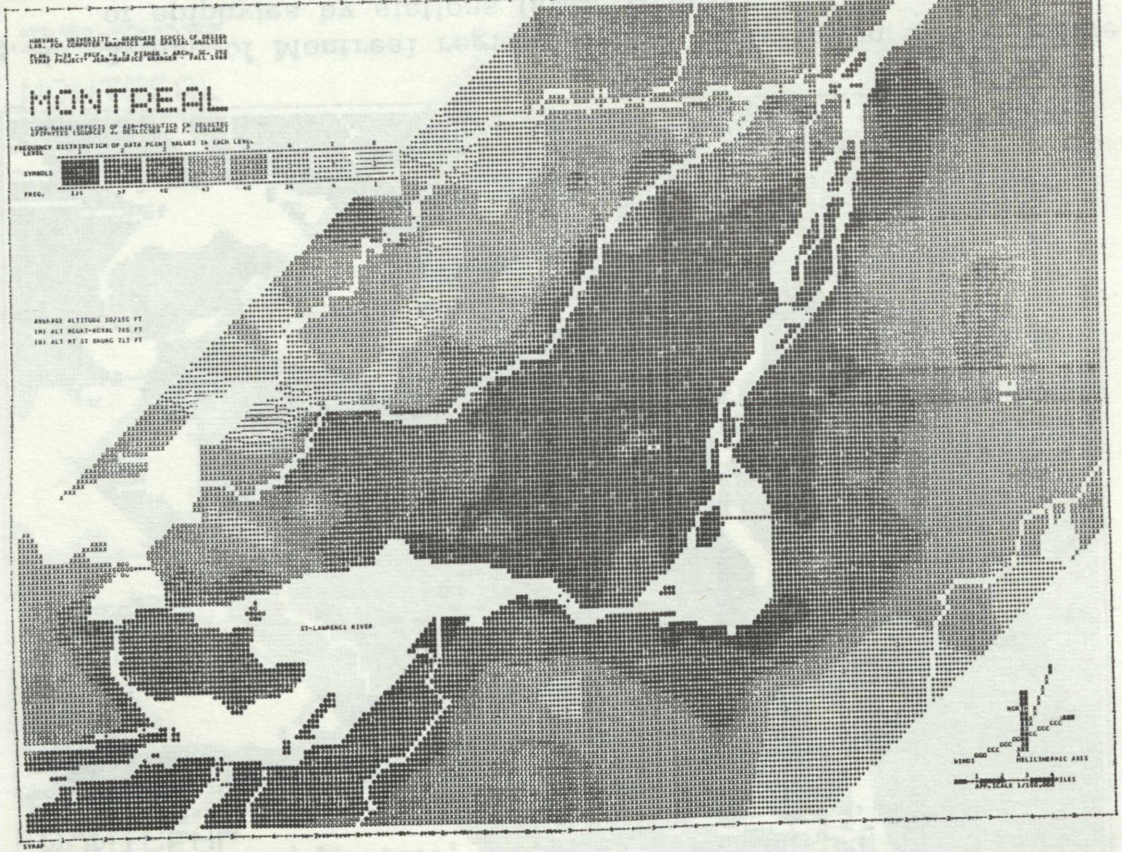

Fig. 3 Symap of Montreal region giving equal value range to the I.A.P. data (after Granger 1970)

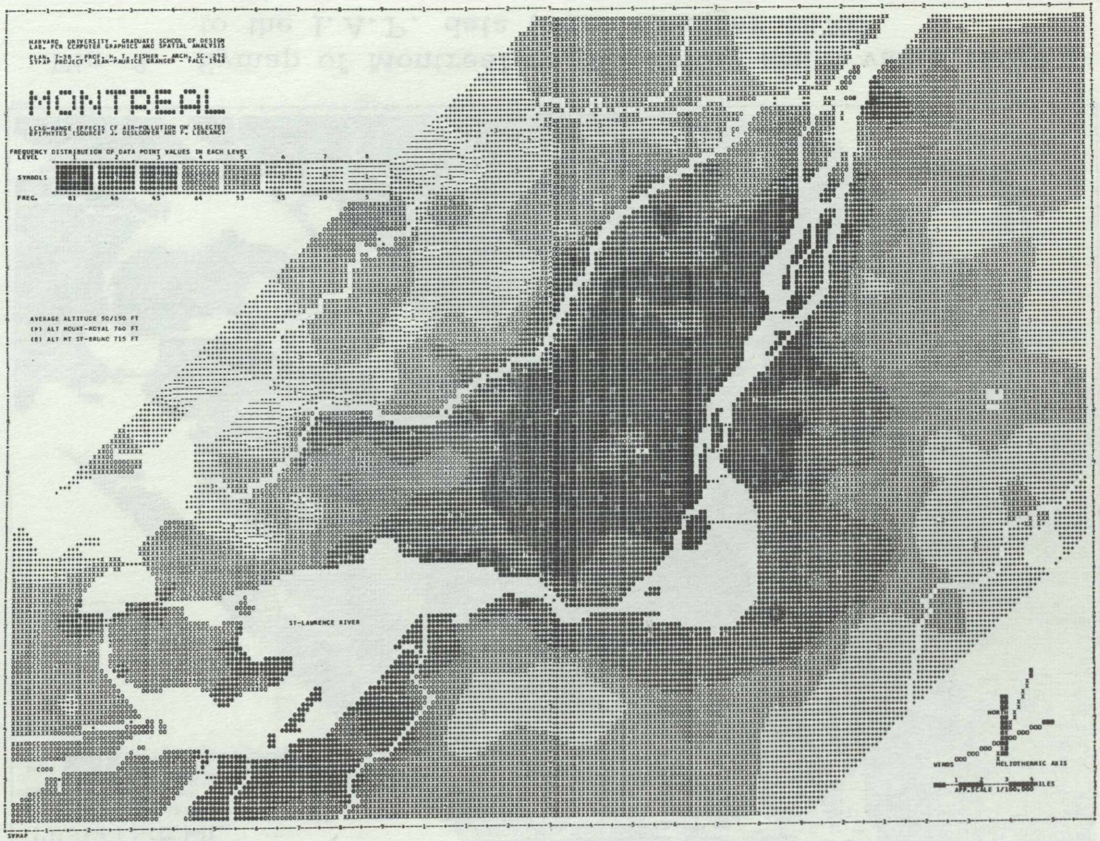

Fig. 4 Symap of Montreal region showing distribution of the number of epiphytes by stations (after Granger 1970)

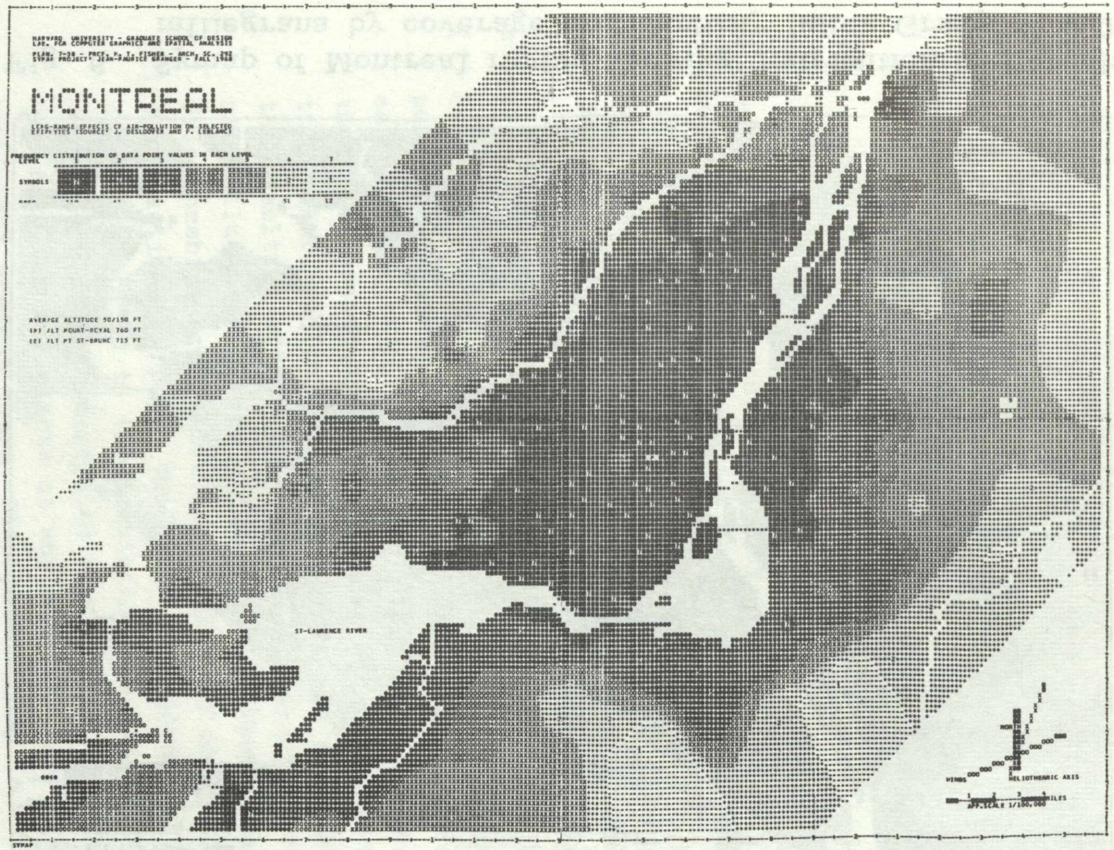

Fig. 5 Symap of Montreal region showing distribution of Physcia millegrana, Physcia stellaris, Xanthoria fallax, and Leskea polycarpa by coverage and fertility (after Granger 1970)

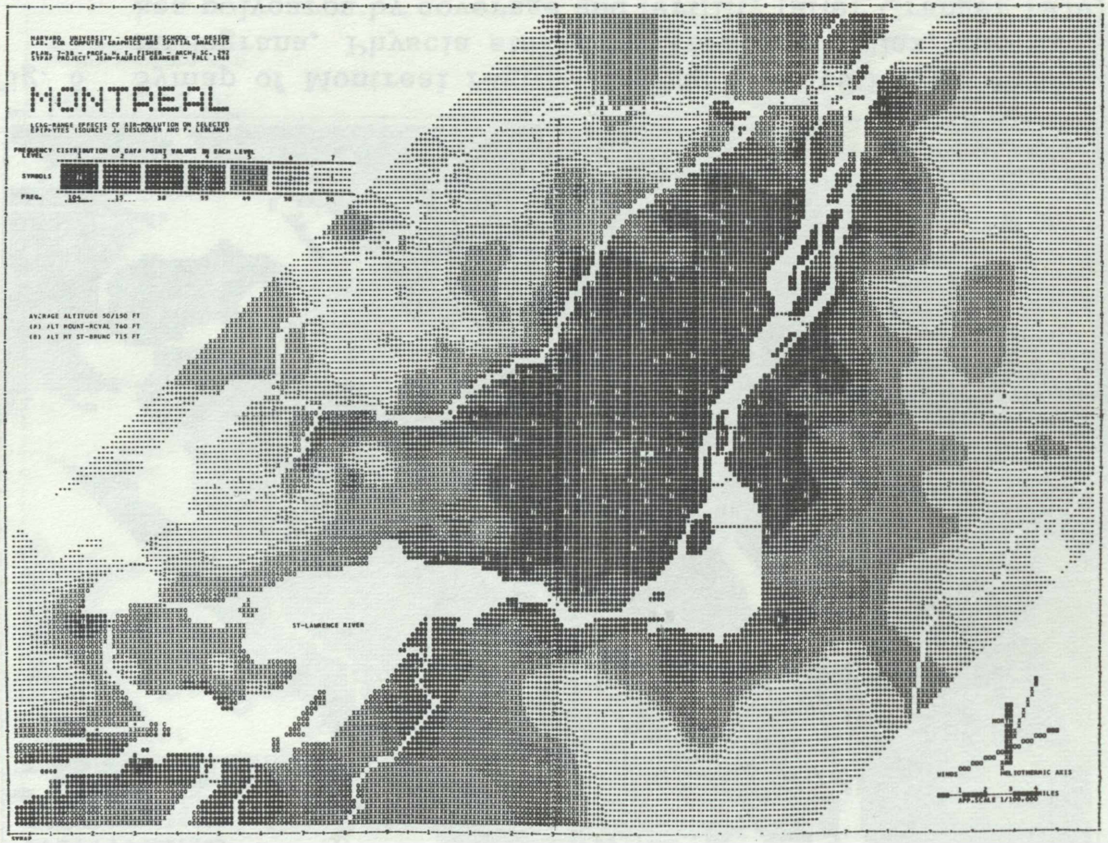

Fig. 6 Symap of Montreal region showing distribution of Physcia millegrana by coverage and fertility (after Granger 1970)

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