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MAPPING LICHEN DIVERSITY AS AN INDICATOR OF ENVIRONMENTAL QUALITY

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In the last decades, several methods were proposed for assessing environmental quality - mainly air pollution - on the basis of lichen data (see chapter 4, this volume). At the end of the 80s the predictivity of 20 different methods with respect to instrumental pollution data was tested in Switzerland using multiple regression [1, 5]. The highest correlation was found with the sum of frequencies of lichen species within a sampling grid of 10 units positioned on the trunks of free-standing trees. This method was immediately and widely adopted in several other countries, esp. Italy and Germany, with some modifications, chiefly concerning the size of the sampling grid. Since 1987, hundreds of studies were carried out with this approach, which led to its standardization in the form of guidelines both in Germany [13], and in Italy [7].

The bioindication method presented here is largely based on the Swiss approach [1, 5], and on the German and the Italian guidelines [7, 13], with several important modifications which were agreed upon during a meeting of the authors in Rome (November 2000), sponsored by the Italian National Agency for the Environment (ANPA). The main modifications concern several elements of subjectivity in the sampling process which were present in both of the original guidelines. They regard mainly the location of sampling sites, the selection of sample trees, and the positioning of the sampling grid on the trunks (see also chapter 9, this volume).

More attention is also paid to vegetational data as a source of information for interpreting lichen diversity patterns, as in the phytosociological approach largely followed in France [11].

1. Aims

- To provide a repeatable and objective method for assessing lichen diversity values (LDV) and for describing vegetation on the bark of trees, based on the frequency of occurrence of lichen species on a defined portion of the trunks.
- To outline zones of different environmental quality.

2. Method

2.1. SAMPLING DESIGN

Several sampling designs are possible, depending on the aims of the study, on its geographical scale, on the characteristics of the survey area, and on the available resources. As a general rule, any element of subjectivity must be avoided in the selection of sample trees and of monitoring sites (hereafter referred to as “sampling units”). A survey of the effects of environmental alteration calls for an even distribution of sampling units, which can be best obtained by locating them according to a geographical grid (see chapter 9, this volume). The following procedure is suggested:

1. Delimit the geographical area to be sampled.
2. Carry out a preliminary survey on the availability of suitable trees before deciding on the tree species and size of the sampling units, in order to avoid many units with no trees.
3. Select a geographical grid for obtaining an even location of sampling units across the geographical area. Sampling units are located at the intersection points of the geographical grid.
4. Choose a sampling area ranging from 0.25 km² (for large-scale studies) to 1 km² (for small-scale studies) which must then be used throughout the survey. The shape of the sampling unit can be rectangular, quadrat, or circular.
5. Establish the number of trees (x) to be sampled in each unit according to the availability of suitable trees (see sampling procedure), and project requirements. Recommended ranges are 4-8 trees for studies where a rather imprecise estimate of lichen data is sufficient, 9-12 when a greater precision is required.
6. If fewer than x trees are available in any area, use the following standard procedure to shift the unit to be sampled:
 - Identify the 8 sampling units adjacent to the original.
 - Move to the unit north and then clockwise until the sampling requirements of x trees are met (Figure 1).

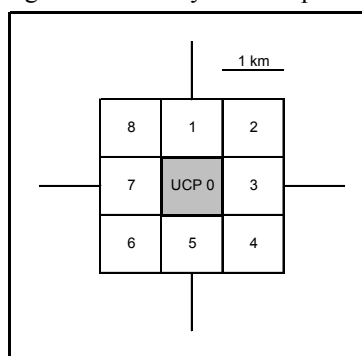


Figure 1. Scheme for shifting the sampling unit when suitable conditions are not found at the originally identified unit (UCP 0). Numbering of quadrants corresponds to shifting priority (after Ferretti [3]).

- In the absence of x trees in any unit, the sampling unit is omitted.
7. When in a sampling unit the suitable trees are more than the number chosen for sampling, there is the need to ensure a documented and statistically sound selection of trees. Different procedures can be adopted, provided they are unbiased (non-subjective). Statistically, the best solution would be to select the trees randomly. This, however, may cause several practical problems. Otherwise, the following procedure is suggested (see Figure 2):
- Define the centre of the sampling unit, and divide the unit into four sectors,
 - Number the sectors clockwise from 1 to 4, starting from the upper right sector,
 - First, for each sector look to the three suitable trees which are closest to the centre of the unit. Two cases may arise:
 - 1) There are at least three suitable trees per sector; this is the ideal situation, and 12 trees can be sampled.
 - 2) There are some sectors with less than 3 suitable trees and others with more than 3 trees. In this case come back to the first sector with more than 3 trees and select new trees until the number of 12 is reached; if not, move to the next sector and so on, until the number of 12 is reached.
- In both cases, the trees closest to the centre of the unit must be selected.

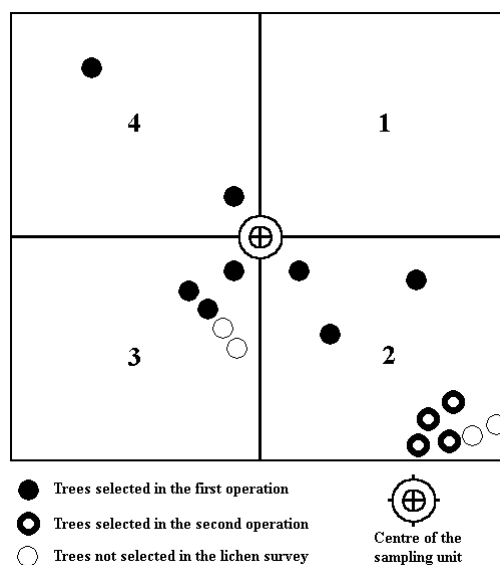


Figure 2. Example of selection of trees in a sampling unit.

2.2. SAMPLING PROCEDURE

1. Select trees of the same species, or with similar bark properties (e.g. pH, water storing capacity, nutrient content) [14]. Selected trees must be free-standing (well-lit), with girths >70 cm and near straight trunks (inclination $<10^\circ$ from vertical).

Trees subject to damage or disturbance from liming/fertiliser, grazing animals etc. should be avoided.

2. Attach the four sampling ladders (each having five 10x10 cm contiguous quadrats) to the trunk at the cardinal points, so that the upper edge of the ladder is 1.5 m above the highest point of the ground (Figure 3). A shift of 20° max clockwise is allowed for individual ladders, to avoid parts of the trunk which are not suitable for sampling.
3. Avoid the following situations:
 - damaged or decorticated parts of the trunk,
 - parts with knots,
 - parts corresponding to seepage tracks after rain,
 - parts with >25% cover of bryophytes.

At least 3 ladders of the grid should be placed, or the tree should be discarded.
4. Record all lichen species in each ladder and their frequency in the 5 quadrats of the ladder (nr. of quadrats in which a species occurs). The list of species with their frequency values in a single ladder constitutes a relevé of lichen vegetation.
5. Each sampled tree should be georeferenced, to permit repetitions of the study (monitoring).

On a local level, the method produces reliable results also with a reduced set of species [13]. This, however, is not suggested here, in view of the potential application of this method throughout Europe.

3. Data analysis

3.1. CALCULATION OF LICHEN DIVERSITY VALUES (LDVs)

1. Within each sampling unit, sum the frequencies of all lichen species at each cardinal point on each tree (i). Thus, for each tree there are four Sums of Frequencies

$$SF_{iN}, SF_{iE}, SF_{iS}, SF_{iW}$$

2. Next, for each cardinal point the arithmetic mean of the Sums of Frequencies (MSF) for sampling unit j are calculated:

$$MSF_{Nj} = (SF_{1Nj} + SF_{2Nj} + SF_{3Nj} + SF_{4Nj} + \dots + SF_{nNj})/n$$

Where:

MSF: Mean of the sums of frequencies of all trees of unit j at a given cardinal point

SF: Sum of frequencies of all the species found at one cardinal point of tree i

N, E, S, W: north, east, south, west

n: number of ladders with a given exposure in unit j

The Lichen Diversity Value of sampling unit j (LDV_j) is the sum of the MSFs of the cardinal points

$$LDV_j = (MSF_{Nj} + MSF_{Ej} + MSF_{Sj} + MSF_{Wj})$$

3.2. MAPPING LICHEN DIVERSITY

Maps of LDVs can be constructed in two different ways:

1. The sampling units are plotted onto the geographical area map. Their LDV values are assigned to classes of lichen diversity (see below). The sampling units are coloured according to the respective class.

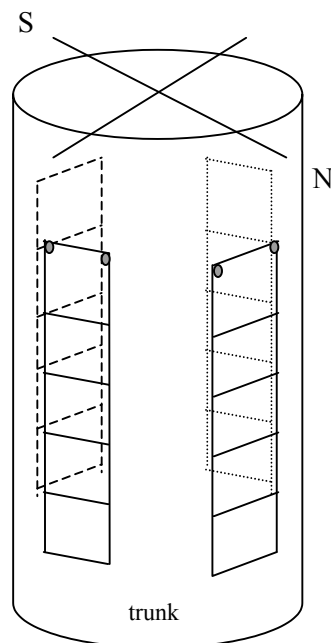


Figure 3. Sampling grid composed of four ladders each with 5 contiguous quadrats.

2. Programs of automatic mapping can be used. These programs calculate interpolations from adjoining points and require careful consideration as to whether the geomorphology of the survey area and the sampling density permit the use of such algorithms (see chapter 9, this volume).

For the subdivision of LDV values into classes which are suitable for mapping we refer to the VDI guidelines [13].

3.3. DETERMINATION OF ENVIRONMENTAL ALTERATION

- Where regional scales of deviation from “natural” conditions are available LDV results can be used to assess magnitude of alteration (see chapter 20, this volume).
- In absence of a regional scale, use the difference between maximum and minimum LDVs within the survey area to create a scale with which to detect a local pattern of environmental alteration. However the magnitude of deviation from naturality cannot be assessed.

3.4. INTERPRETATION OF RELEVÉ DATA

- Use multivariate analysis to distinguish groups of species with similar ecological

behaviour, and groups of relevés with a similar floristic composition (communities) e.g. nitrophytic/non-nitrophytic to reveal patterns of eutrophication/acidification [12].

- Investigate the effect of aspect on lichen distribution.
- Determine local sensitivity values for lichens in relation to atmospheric conditions to map air quality patterns [4, 9, 10].
- If available for the survey area, use ecological indicator values, e.g. for pH to reveal acidification, etc. [2, 6, 8, 14].
- Use average frequencies of selected indicator species in each sampling unit to make distribution maps of those species, in the same way as suggested for the LDVs.

4. Data Quality control

- Investigations performed according to this method require personnel with the necessary expertise. Standards of quality assurance should be followed, and National Authorities should ensure that operators are properly trained and inter-calibrated.
- Several sampling designs are possible, depending on the aims of the study, on its geographical scale, on the characteristics of the survey area, and on the available resources. As a general rule, any element of subjectivity must be avoided in the selection of sample trees and of monitoring sites.

5. Application

This method supplies information on the long-term effects of air pollutants, eutrophication, anthropization and climatic changes on sensitive organisms. It can be applied in the vicinity of an emission source to provide proof of the presence of air pollution and to detect its causes, or, on a larger scale, for detecting patterns and hot-spots of environmental stress. Its repetition at the same sites permits to monitor the effects of environmental changes.

6. Limitations

In areas where trees are infrequent it is not possible to use this method. LDVs should not be uncritically compared among floristically and climatically very different areas. In particularly dry areas (e.g. parts of the Mediterranean region) the method cannot be applied.

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