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THE LICHEN VEGETATION ON THE CATHEDRAL OF ORVIETO (CENTRAL ITALY)*

P.L. NIMIS & M. MONTE

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Abstract: the lichen vegetation of the Cathedral of Orvieto (Central Italy) has been studied on the basis of 29 phytosociological releves carried out on different parts of the church, and on different substrates. The species by releves matrix has been submitted to classification and ordination to detect different community-types and to study possible ecological gradients. The ecology of the community-types has been studied by means of the ecological indices derived from Wirth (1980). The main causes of lichen growth in different parts of the church, the main aesthetic damages, and the possible measures for eliminating and preventing lichen growth are discussed.

Riassunto breve: LA VEGETAZIONE LICHENICA DEL DUOMO DI ORVIETO. La vegetazione lichenica del duomo di Orvieto è stata studiata sulla base di 29 rilievi fitosociologici effettuati in diverse parti della chiesa, e su diversi substrati. La matrice delle specie e dei rilievi è stata sottoposta a classificazione ed ordinamento al fine di individuare diversi tipi di vegetazione e di evidenziare possibili gradienti ecologici. L'ecologia dei diversi tipi di vegetazione è stata studiata utilizzando le diagnosi ecologiche proposte da Wirth (1980) per le singole specie. Vengono discussi le principali cause che determinano la crescita dei licheni nelle diversi parti del Duomo, i principali danni estetici da essi creati, e possibili misure di intervento per eliminare e prevenire la crescita dei licheni nella parti maggiormente colpite.

Introduction

Stone monuments are frequently colonized by lichens. This implies several conservation and restoration problems, for whose solution the following points are of importance:

a) Acquisition of information on the type of damages caused by lichens. The damage may be purely aesthetic (chromatic alterations), or chemico-physical (alterations of the properties of the rock surface);

b) choice of elimination techniques. These may be based on the application of biocides, on mechanical means, or on both. The choice of the best techniques depends on knowledge related to points a), c), d), and e);

c) information on the consequences of elimination. These are particularly evident in the case of endolithic lichens (Nimis et al. 1987), where the elimination of the

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lichens implies the abrasion of a thin rock layer;
d) information on the causes of lichen growth. Many interventions risk to be ephemerous if the main causes of lichen growth are not eliminated. This is particularly evident in the case of nitrophytic lichens, which have a relatively rapid growth; their elimination should be accompanied by a reduction of the main eutrophication sources (e.g. bird excrements);
e) information on the reproductive strategy of lichens. The purely mechanical elimination of some sorediate species might be not sufficient, since it does not allow the elimination of all small vegetative propagules (soredia). In such cases the intervention should be accompanied by the application of appropriate biocides.

This study concerns the lichen vegetation of Orvieto's Cathedral, in Central Italy (Umbria Region, Province of Perugia). Its main aim is to acquire informations on: a) types of lichen vegetation present on the monument, b) their location on the monument, c) main ecological factors affecting lichen growth on different parts of the monument, d) main types of damages caused by lichens. Such informations are indispensable to start any intervention aimed at eliminating lichen growth.

Data and Methods

This study is based on 29 phytosociological releves carried out in different parts of Orvieto's Cathedral. The Cathedral is one of the most famous examples of Italian Gothic; it is located at the top of Orvieto's hill, at ca. 325 m; the church is oriented in an east-west direction, the main façade facing west. The walls are built with alternating bands of white limestone and black basaltic rocks; marble has been used chiefly to decorate the main façade.

Each releve consists in a list of species present on a surface of 20 x 20 cm, A cover value has been assigned to each species, according to the following scale:

+ = less than 1%
1 = 1-20%
2 = 21-40%
3 = 41-60%
4 = 61-80%
5 = 81-100%

The location of the releves on the church is as follows:
Releves 1 to 4: Statues under the tympanum of the main façade (marble).
Releves 5 to 12: Upper part of the lower tympanum (travertine).
Releves 13 to 17: lower part of the lower tympanum.
Releves 18, 26 to 29: basement at the northern side of the Church (limestone), at 50 cm aboveground.
Releves 19, 22: northern side of the church, at 1.5-2.5 m, on limestone.
Releves 20, 21, 23 to 25: northern side of the church, at 1.5-2.5 m, on basaltic rock.

The southern side of the church hosts a very poor and fragmentary lichen ve-

Tab. 1 - Phytosociological table of lichen vegetation. The releves and the species are ordered as in the respective dendrograms.

Releve Group Nr.	1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 4 4 4 4 4 5 5 5 5 5
Releve Nr.	1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
	5 3 7 4 1 7 6 8 6 5 0 9 2 2 9 7 6 8 8 9 4 2 3 1 5 4 1 0 3
Sp.Nr.	
12 Physcia orbicularis	1 2 + 3 + + 3 1
11 Caloplaca teicholyta	+ + + + + +
36 Lecanora dispersa	+ + + +
8 Xanthoria calcicola	1 1 + 1 1
20 Physcia adscendens	+ +
29 Physcia dubia	+ +
18 Xanthoria parietina	+ 1
17 Lecanora muralis s.str.	+ 2 +
19 Physconia grisea	+
7 Caloplaca flavescens	3 1 3 + 1 1 4 + 2 1 + +
5 Caloplaca granulosa	+ + 1 + 1 + +
6 Caloplaca saxicola	+ 1 1 1 + 1 + 1 + 3 1 + + + +
4 Lecanora albescens	1 1 2 2 2 4 1 3 + 1 1 + 3 1 1 1 + + 1 + + + 1
2 Caloplaca biatorina v.gyalolechiodes	+ 1 + + + 1 + 1 + + 1 3 2 3 2
35 Rinodina bischoffii	+ +
34 Caloplaca citrina	+ + +
32 Catillaria lenticularis	+ + +
22 Verrucaria marmorea	1 2 3 3 1
23 Verrucaria parmigera	+ + 1
33 Lecania turicensis	+ +
16 Verrucaria nigrescens	+ + + + + + 1 + 1 +
3 Candelariella aurella	+ + + + + + + 1 +
25 Lecanora muralis v.versicolor	+
21 Aspicilia contorta	+ 1 1
14 Caloplaca lithophila	+ +
1 Caloplaca erythrocarpa	+ + + +
13 Aspicilia calcarea	+ 1 + + + 1 1 1
9 Caloplaca aurantia	+ 1 + + + 3 2 2 + 1
15 Aspicilia hoffmannii	+ + + +
10 Candelariella medians	+ + + + + +
28 Haematomma ochroleucum v. ochrol.	1 1 + + +
37 Haematomma ochrol. v. porphyrium	3 3 + 1
26 Tephromela atra	+ + 1 2 +
31 Lecidella stigmatea	+ 1 1 +
30 Candelariella vitellina	+ + 1 +
27 Lecanora sulphurea	+ + 2 2 1
24 Diploicia canescens	2 + 1 +
38 Dirina massiliensis f. sorediata	+ + + + +

getation, so that no releve has been carried out there. Other parts of the church were not accessible during the survey period.

The matrix of the species and of the releves (Tab. 1) has been submitted to multivariate analysis in order to tipify the vegetation and to quantify the relations between its compositional variation and the variation of some main ecological factors. Ecological information has been derived, in an indirect way, from the ecological diagnoses proposed by Wirth (1980), regarding pH requirements, tolerance to eutrophication, moisture requirements, and light requirements of the species. The diagnoses have been transformed into Ecological Indices, on an or-

Tab. 2 (a-d): occupancies of different ecological indices' classes (expressed as percentages), subdivided by releve groups. a) pH index, b) eutrophication index, c) hygrophytism index, d) photophytism index.

Releve Groups nr.	1	2	3	4	5
A - pH 3.4-4.0	.....	.....	.....	.....	13.3
B - pH 4.1-4.8	.....	.....	.....	.....	30.0
C - pH 4.9-5.6	4.8	.....	.....	.....	46.6
D - pH 5.7-6.9	15.9	4.4	.....	.....	40.1
E - pH 7.0	44.4	33.3	46.1	42.1	20.0
F - pH 7.1-8.5	55.5	51.1	46.1	100.0	26.6
G - pH > 8.5	74.6	100.0	100.0	85.7	20.0
a)					
A - anitrophytic	.....	8.8	28.2	.....	43.3
B - moderately nitrophytic	53.9	64.7	58.9	84.7	93.3
C - rather nitrophytic	98.4	71.1	66.6	100.0	40.0
D - very nitrophytic	76.1	53.3	58.9	84.7	20.0
E - extremely nitrophytic	22.2	26.6	23.5	42.8	.....
b)					
A - rather hygrophytic	9.5	8.8	17.9	.....	33.3
B - mesophytic	53.9	37.3	38.5	.....	100.0
C - rather xerophytic	100.0	91.1	89.7	100.0	70.0
D - very xerophytic	58.7	64.4	23.1	100.0	20.0
c)					
A - moderately photophytic	47.6	97.7	41.0	42.8	60.0
B - photophytic	92.1	84.4	74.3	100.0	100.0
C - very photophytic	95.2	61.5	48.7	100.0	86.6
d)					

dinal scale, as proposed by Nimis & Dallai (1985) and Nimis et al. (1987). Tab. 2 reports the incidence of the species in each index-class for each releve group obtained by numerical classification of the data in Tab. 1, expressed as percentages of the total occupancies. Data elaboration may be summarized as follows:
1) Classification of releves and of species, to obtain releve groups with similar composition (vegetation types), and groups of species with similar ecological behaviour. The algorithm used for classification is Complete Linkage Clustering (Anderberg, 1973), using the Correlation Coefficient as resemblance measure, on binary data (program package by Wildi & Orloci, 1980).
2) Canonical Concentration Analysis (AOC) on the contingency table of the groups of species and of releves, to quantify the correlation among groups. The program used is AOCRO (Feoli & Orloci, 1979).
3) Reciprocal Ordination of species and releves, carried out on the data of Tab. 1, trasformed by deviation from expectation, using Cross Product as a resemblan-

ce measure, to detect possible ecological gradients, and to study the response of single species to these gradients. (program package by Wildi & Orloci, 1980).
4) Canonical Concentration Analysis (AOC) on the data of Tab. 2 (a-d), to order the releve groups along four main ecological gradients (pH, tolerance to eutrophication, humidity, light). The program used is AOCRO (Feoli & Orloci, 1979).

The nomenclature of the species follows Nimis et Poelt (1987).

Results

The dendrograms of the species and of the releves, and the contingency table of species and releve groups are shown in Fig. 1. The classification of the species produces 5 main species groups (A-E) at a fusion level of 0.01 of the Correlation Coefficient. The classification of the releves forms 5 main releve groups (1-5) at a fusion level of 0.1 of the Correlation Coefficient. The correlations between species and releve groups are shown in Fig. 2, that reports their position in the space defined by the first two canonical variates of AOC. These results may be summarized as follows:

Species group A: among the most frequent species are *Physcia orbicularis, Ca-*

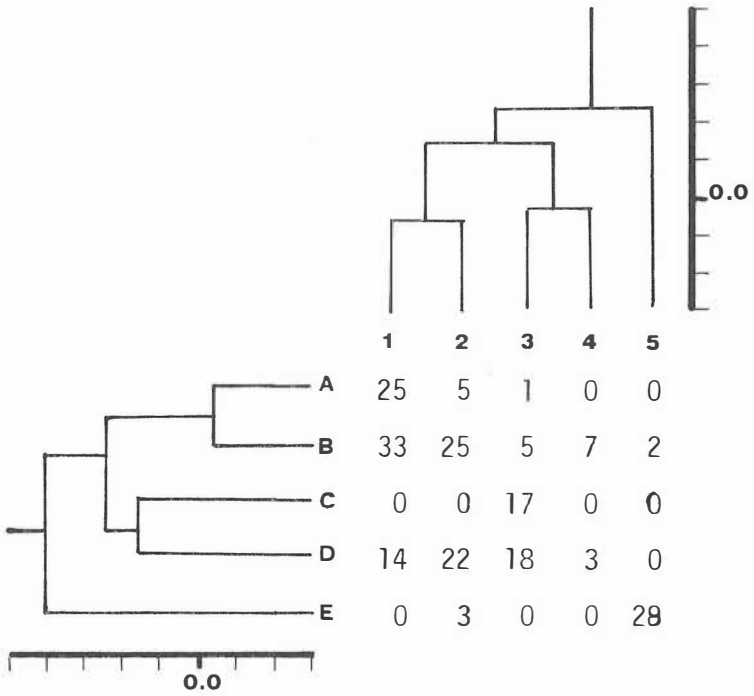

Fig. 1 - Dendrogram of the releve groups (numbers) and of the species groups (letters), with the contingency table of releve and species groups, obtained by numerical classification of the data in Tab. 1.

loplaca teicholyta, Lecanora dispersa, Xanthoria calcicola, Lecanora muralis s. str. This group is correlated with releve group 1, including the releves carried out on the lower tympanum of the main façade.

Species group B: among the most frequent species are: *Caloplaca flavescens, Caloplaca granulosa, Caloplaca saxicola, Lecanora albescens, Caloplaca biatorina* var. *gyalolechioides.* This group is correlated with releve groups 1, 2 and 4 (lower tympanum, calcareous belts above 1.5 m aboveground at the northern side of the church, and statues under the upper tympanum).

Species group C: among the most frequent species are: *Verrucaria marmorea, Catillaria lenticularis, Caloplaca citrina.* This group is correlated with releve group 3 (calcareous basement of the northern side of the church).

Species group D: among the most frequent species are: *Caloplaca aurantia, Aspicilia calcarea, Verrucaria nigrescens, Candelariella aurella.* This group has the highest correlation with releve groups 2 and 3.

Species group E: among the most frequent species are: *Dirina massiliensis* fo. *sorediata, Tephromela atra, Candelariella vitellina, Lecanora sulphurea, Haematomma ochroleucum.* This group has a strong correlation with releve group nr.

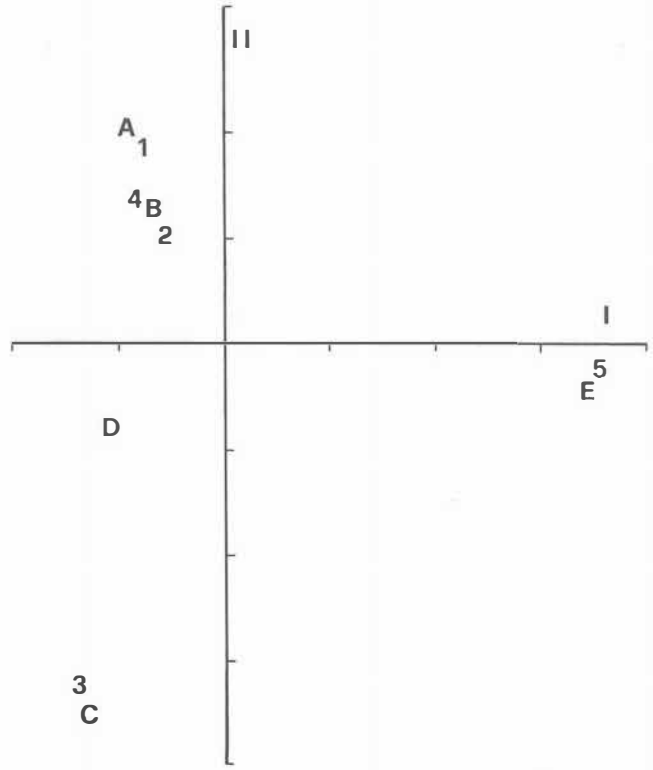

Fig. 2 - Arrangement of releve group (numbers) and species group (lettes) points according to the two first canonical variates of AOC, performed on the contingency table of Fig. 1.

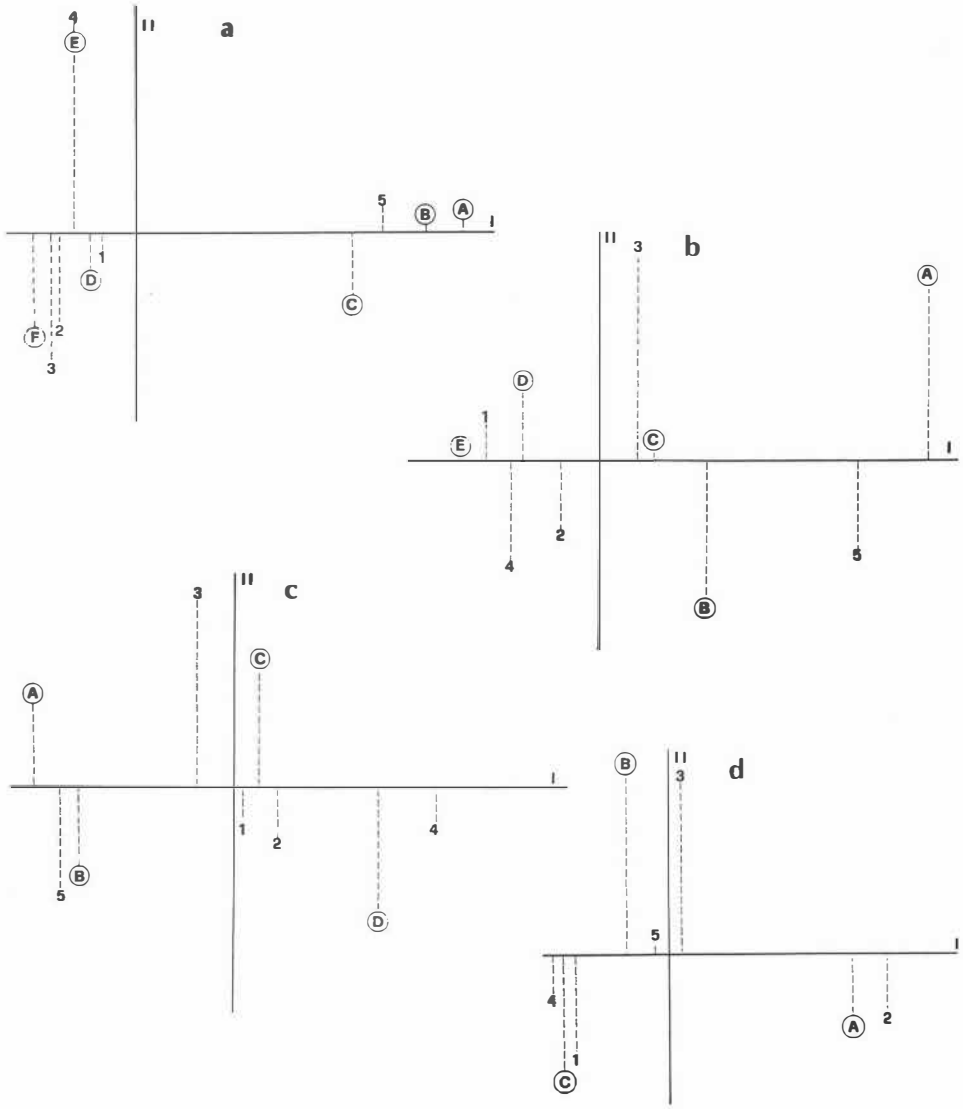

Fig. 3 - Arrangement of releve group points (numbers) and
a) pH-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2a.
b) nitropyhtism-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2b.
c) moisture-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2a.
d) photophytism-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2a.

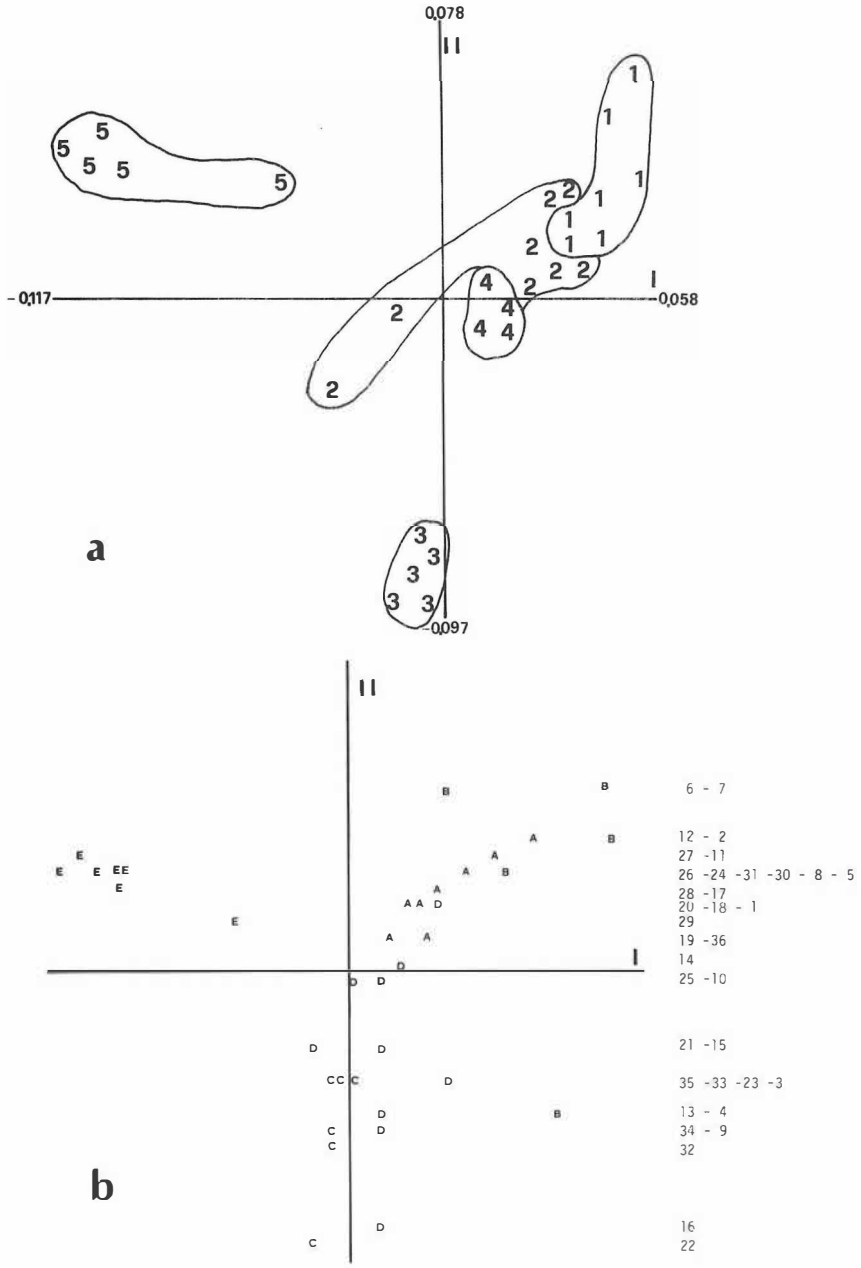

Fig. 4 - Reciprocal ordination of: a) releves b) species, performed on the data of Tab. 1. In Fig. 4a the releve groups are numbered as in Tab. 1. In Fig. 4b the species groups, and the single species are numbered as in Tab. 1.

5 (basaltic substrate, northern side of the church).

The ecological characterization of the 5 releve groups is shown in Fig. 3 (a-d), reporting the arrangement of the releve groups and of the classes of ecological indices in the space defined by the first two canonical variates of AOC. The results may be summarized as follows:

pH requirements (Fig. 3a): first canonical variate: 92.6% of the total chi square, second canonical variate: 4.83%. Sequence of the releve groups along the first canonical variate (from basiphytic to acidophytic): groups nr. 4, 3, 2, 1, 5. Releve group nr. 5 is well distinguished for the prevalence of subacidophytic species (basaltic substrate).

Eutrophication (Fig. 3b): first canonical variate: 90.9% of the total chi square, second variate: 5.06%. The sequence of the releve groups along the first canonical variate (from strongly nitrophytic to anitrophytic) is: 1, 4, 2, 3, 5. Releve groups 1, 4, and 2 are characterized by the prevalence of nitrophytic species (eutrophication of the substrates by bird excrements).

Moisture requirements (Fig. 3c): first canonical variate: 92.8% of the total chi square, second variate: 5.73%. Sequence of the releve groups along the first variate (from hygrophytic to xerophytic): groups nr. 5, 3, 1, 2, 4. The less xerophytic groups are nr. 5 and nr. 3, i.e. those including releves carried out on the northern façade of the church.

Light requirements (Fig. 3d): first canonical variate: 93% of the total chi square, second variate: 6.99%. Sequence of the releve groups along the first variate (from little to very photophytic): groups nr. 2, 3, 5, 1, 4.

According to these results, the 5 releve groups may be ecologically characterized as follows:

Group 1: neutrophytic, very nitrophytic, rather xerophytic, very photophytic.
Group 2: basiphytic, nitrophytic, rather xerophytic, little photophytic.
Group 3: basiphytic, moderately nitrophytic, rather xerophytic, moderately photophytic.
Group 4: very basiphytic, very nitrophytic, very xerophytic, very photophytic.
Group 5: subacidophytic, anitrophytic, rather hygrophytic, moderately photophytic.

The reciprocal ordination of releves and species is shown in Fig. 4 (a: releves, b: species). The groups of species and of releves obtained by classification are still recognizable in the ordination. The first principal component separates releve group nr. 5 (basaltic substrate) from all the others (calcareous substrates). The second principal component separates releve group nr. 3 from group 1, 2 and 4. This separation does not seem to be justified on the basis of the ecological characterization of this releve group. The reason for its distinction along the second variate is probably the different lithological character of the limestone of the northern basement, which has a finer crystalline texture with respect to the other calcareous substrates present on the church. Some species which characterize releve group nr. 3 (e.g. *Verrucaria marmorea, V. parmigera)* prefer to grow on compact limestone. The ordination of the species (Fig. 4 b) should be interpreted in

conjunction with the ordination of the releves: the arrangement of the species points in the space defined by the two principal components reflects their correlation with the compositional gradient revealed by the ordination of the releves.

Discussion

Southern side

The southern façade has a very poor lichen cover, both on the basaltic and on the calcareous belts. There are a few, isolated thalli of *Lecanora dispersa* and *Candelariella aurella* on limestone, scarce individuals of *Candelariella vitellina* on basalt. The reason of the scarce lichen growth is probably the strong insolation, and consequently the strong evaporation; this renders the environment too dry for the development of a rich lichen vegetation. The few lichen species occurring on this side of the church have very small, fragmentary thalli, so that the aesthetic damage is practically non-existent. No intervention is needed on the southern side of the church.

Main Façade (facing west)

The densest lichen cover is concentrated on the lower tympanum. Bright coloured species (yellow-orange) are dominant, which implies a strong chromatic alteration of the stone. Most of the species are nitrophylous: the main cause for their growth is the frequent presence of birds. Lichen growth is concentrated on the tympanum since this is made up of very porous calcareous rock; the porosity of the substrate slows down evaporation and helps the concentration of nitrogen compounds. The young lichen thalli start their development within small niches of the rock, from which they spread later over the entire surface. Parts of the tympanum have been substituted, and replaced with hard limestone, where lichens are very scarce. Given the rapid growth of most nitrophytic species, the simple elimination of lichens will have probably ephemerous results, if not accompanied by other measures, such as the treatment of the rock surfaces with synthetic protective substances, the protection against rain water or the elimination of birds. Besides the upper tympanum, nitrophytic lichens are present also in some parts of the façade where there is periodical percolation of water. The chromatic alteration is rather evident, although these surfaces are generally small; also in this case the removal of lichens should be accompanied by a removal of the causes of their growth, i.e. of water percolation.

Other parts of the main façade with a rather dense lichen cover are the statues located below the upper tympanum and part of the marbles. The statues are colonized by a few species, chiefly *Caloplaca biatorina* var. *gyalolechioides* and *Candelariella aurella*. The total cover is low, and the chromatic alteration is not particularly evident, notwithstanding the bright colour of the thalli of *Caloplaca*. On the statues, *Caloplaca* is most abundant on rain-protected surfaces; being a relatively slow-growing xerophytic lichen, its elimination should be less epheme-

rous than in the case of the nitrophytic lichens.

Northern side

Calcareous basement: it is dominated by endolithic lichens, chiefly *Verrucaria parmigera* and *V. marmorea*. The chromatic alteration is not particularly serious (pale pink and whitish gray). Any measure to remove the lichens runs the danger of secondary effects, which might be more serious than the damage deriving by lichens themselves. Even the application of biocides, killing the lichen within the rock, may produce, on the long run, a strong alteration of the rock surface, which becomes very porous and sensible to corrosion, besides assuming a pure white colour contrasting with that of the other parts of the building.

Calcareous bands: the greatest aesthetic damage is produced by nitrophytic lichens, chiefly *Caloplaca aurantia* (orange colour). The cause of the growth of these lichens is the presence of water percolating from the windows of the church. To hinder lichen growth one should eliminate this percolation, which should be possible with rather simple measures. The calcareous bands not interested by water percolation are colonized by almost pure populations of *Dirina massiliensis* fo. *sorediata*, which, owing to its white thallus, does not produce any chromatic alteration of the surfaces; its presence on the northern side of the church is probably related to lower evaporation rates, and hence to higher humidity with respect to the southern side.

Basaltic bands: the lichens growing on basalt are responsable of the greatest aesthetic damage on the whole church. The dominant species. *Haematomma ochroleucum* var. *porphyrium* and *Tephromela atra*, have a whitish thallus covering relatively large surfaces. The result is that on most of the northern side of the church the characteristic alternation of white and black bands is almost completely lost. The mechanical removal of lichens is difficult, owing to the uneven surface of the basaltic rock. Furthermore, *Haematomma ochroleucum* produces abundant soredia, which should be eliminated to prevent further lichen growth after the intervention.

Conclusions

The lichen vegetation on Orvieto's Cathedral is concentrated on the lower tympanum of the main façade, and on the northern side of the church. The southern side is almost devoid of lichens, probably because of its high aridity (strong insolation). The principal cause of lichen growth is the eutrophication of the subsrates by bird excrements, which are spread by percolating water. On the main facade lichen cover is densest on the tympanum, because this structure is made of porous calcareous stone. On the northern side the less arid conditions allow lichens to grow also on more compact stones (compact limestone and basalt). Lichens should be removed from the tympanum (which presently is orange-coloured by the presence of several nitrophytic lichens), and from the basaltic bands of the northern façade, which have lost their black colour because of the dominance of

light-coloured lichens. Lichen removal should be accompanied by measures preventing their further growth, chiefly by a better regulation of the water percolating from the upper parts of the church.

Riassunto. La vegetazione lichenica del Duomo di Orvieto è stata studiata sulla base di 29 rilievi fitosociologici, effettuati in varie parti della chiesa, su diversi substrati. La matrice delle specie e dei rilievi è stata sottoposta a programmi di analisi multivariata, al fine di individuare tipi diversi di vegetazione e possibili gradienti ecologici. L'ecologia della vegetazione è stata studiata per via indiretta utilizzando gli indici ecologici di Wirth (1980). Le parti del Duomo di Orvieto maggiormente colonizzate da licheni sono il timpano della facciata principale e tutto il lato nord della chiesa. Sul timpano ed in alcuni punti della facciata nord la causa principale dell'instaurarsi dei licheni è data dall'eutrofizzazione del substrato da parte di uccelli che frequentemente si posano sulle parti alte della chiesa. L'eutrofizzazione si diffonde ad opera di acque percolanti, che scolano, in alcuni punti, direttamente sui muri della chiesa. Sul lato nord, le condizioni di minore xericità fanno si che i licheni coprano vaste superfici. Di particolare gravità è l'attacco, da parte di specie a tallo di colore chiaro, delle bande basaltiche, per cui si perde l'effetto estetico dato dalla caratteristica alternanza di bande scure e chiare. Gli interventi principali dovrebbero interessare il timpano della facciata principale e le bande di basalto. Si sottolinea che per una maggior efficacia degli interventi di asporto, questi dovrebbero venir accompagnati dall'eliminazione delle principali cause della crescita dei licheni; si ritiene che una migliore regolazione degli scoli d'acqua piovana sulla chiesa potrebbe determinare una sensibile riduzione dei licheni nitrofili a tallo vivacemente colorato.

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Authors' Addresses:

Prof. Dr. Pier Luigi NIMIS
Dipartimento di Biologia
Università di Trieste
Via A. Valerio 32
I 34127 TRIESTE

Dr.ssa Michela MONTE
C.N.R. - Centro Conservazione Opere d'Arte
Via Monte d'Oro 28
I 00186 ROMA