PLANT BIOSYSTEMS, **132** (1) 53-61, 1998

Lichen-induced chromatic changes on monuments: a case-study on the Roman amphitheater of Italica (S. Spain)

P.L. NIMIS, M.R.D. SEAWARD, X. ARIÑO and E. BARRENO

received 24 February 1998; revised version accepted 19 May 1998

ABSTRACT - Based on classification and ordination of vegetational data recorded on the Roman amphitheater of Italica (S. Spain), the compositional variation of lichen communities is related to the main ecological parameters: type of substratum, solar irradiation and eutrophication. The data were further processed by a program of automatic mapping, to produce a model showing the main patterns of lichen-induced chromatic changes within the amphitheater.

KEY WORDS - Lichens, biodeterioration, ecological gradients, monuments, Italica, Spain

Ancient monuments and historic architecture are particularly interesting in terms of the rich and varied lichen floras they often support (NIMIS *et al.,* 1992). Interest has been mainly concerned in recent years with the conservation of the works of art, lichens being particularly powerful weathering agents (SYERS & ISKANDER, 1973; JONES & WILSON, 1985; SEAWARD, 1996). Besides biodeterioration phenomena, one of the commonest effects of lichen growth on stone monuments is the chromatic modification of stone surfaces, which is often very pronounced, due to the rich colour palette exhibited by lichen thalli. Sometimes such phenomena are so evident as to impair the aesthetic appreciation of important architectural details (see e.g. NIMIS & MONTE, 1988). Chromatic changes could even affect biodeterioration, since dark colours may cause higher temperatures at the lichen-rock interface in situations of high solar radiation. According to GARTY (1990), the colonization of walls by litho-microorganisms not only causes local aesthetic disfigurement, but also causes a remarkable increase in the temperature on or near areas invaded by such microcolonizers; black surfaces caused by cyanobacteria on mortar walls in Israel were up to 8°C warmer than the non-colonized areas. Such phenomena may have an influence on biodeterioration rates: it is well known that one of the main causes of biodeterioration by some lichens is the alternate cycle of drying and wetting, which is strongly temperature-dependent (SEAWARD, 1988). The simple removal of lichens from monuments is likely to be ephemeral if some of the main causes favouring lichen growth are not eliminated. This suggests that, in order to plan adequate restoration measures, it could be important to map lichen-induced chromatic changes on a monument, and to relate chromatic patterns to ecological gradients. Although detailed lichen lists supported by casual ecological observations are to be found in many papers, only limited work has been done in terms of numeric analyses and phytosociological investigations (e.g. Nimis *et al.,* 1987; Nimis & Monte, 1988). Ancient monuments, due to their regular forms, are also ideal objects for studies on the compositional variation of lichen vegetation in terms of ecological gradients (Tretiach *et al.,* 1991; Tretiach & Monte, 1991).

The ancient Roman town of Italica, near Sevilla in southern Spain, is of particular interest for the ecological-vegetational analysis of lichens growing on rocks, and for studies on the chromatic effects of lichen growth on monuments. At Italica, lichens are abundant on statues, buildings, and especially on mosaics. Lichen growth on mosaics creates serious threats to their conservation, and the first lichen studies at Italica were devoted to this problem (García-Rowe & Sáiz-Jiménez, 1988; Puertas *et al.*, 1993). The abundant lichen vegetation developing on several buildings, on the contrary, is not very harmful to the rock surface, but it often results in evident chromatic changes. The present case-study was carried out on the Roman amphitheater of Italica. Its aims were to investigate ecological gradients and to determine the environmental preferences of specific lichens such as (1) substrata, which although superficially homogeneous, were actually composed of a fine mosaic of calcareous and siliceous components, the whole subjected to varying degrees of dustiness and/or eutrophication; and (2) aspect, the ellipsoid nature of the amphitheater providing almost full compass orientation and various degrees of exposure. Based on multivariate analysis of vegetation data, and on a program of automatic mapping, we analyzed the relationships between compositional variation of the vegetation, some main ecological gradients, and the chromatic modifications of the stone, producing, for the internal part of the amphitheater, the first example of a model of lichen-induced chromatic changes.

SITE, MATERIALS AND METHODS

Italica, a Roman city near Sevilla in southern Spain, was founded by Scipio in 206 BC. It flourished, with a population of 20,000 to 30,000 in the 2nd century AD,

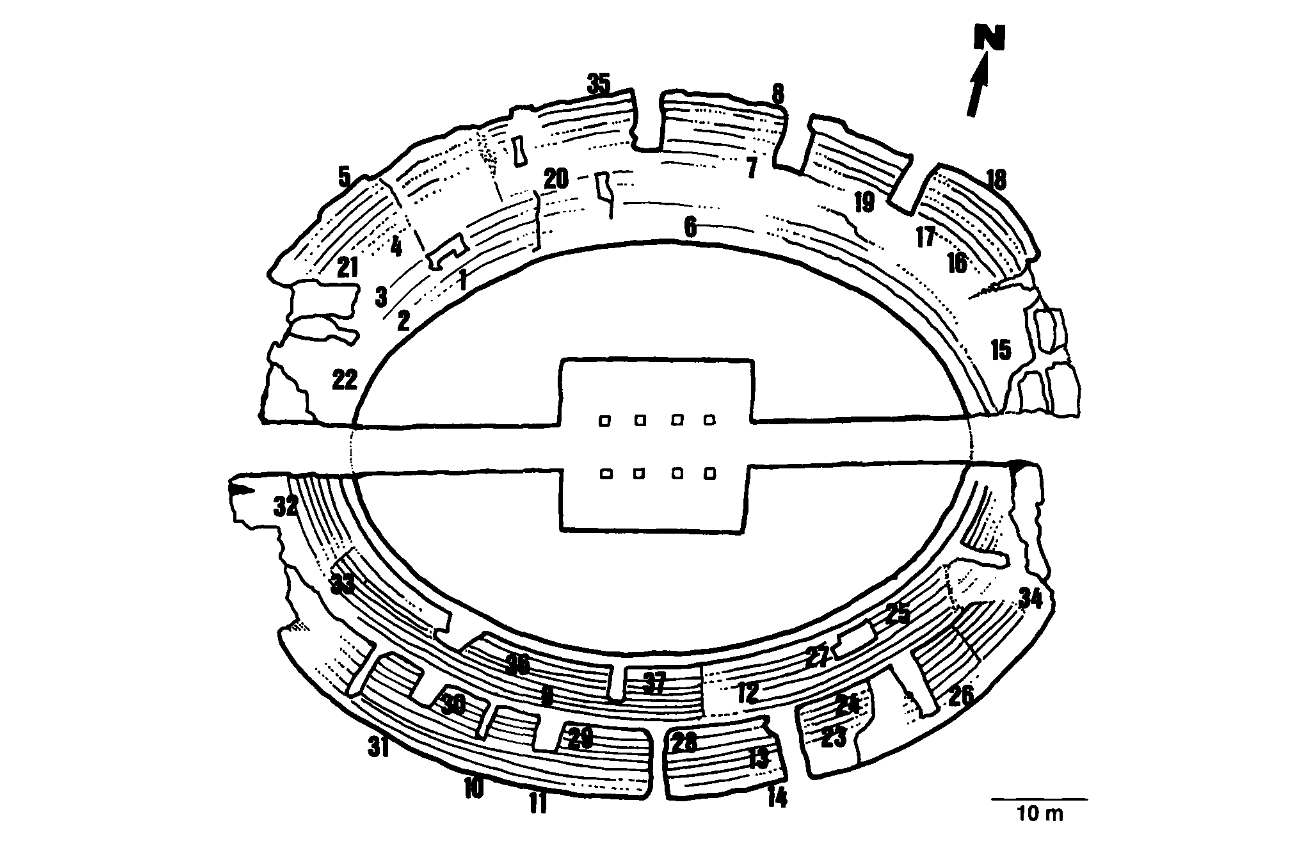

Figure 1 - Schematic plan of the Roman amphitheater of Italica, showing the location of the relevés (numbered as in Table 1).

during which time the amphitheater, designed to accommodate 10,000 people, was built. Preliminary excavations carried out in the 18th century and in more detail in the 19th and 20th centuries revealed a very large number of houses and public buildings, including a reasonably well preserved amphitheater. The amphitheater is situated between 8 m and 25 m above sea level in a sedimentary region of the River Guadalquivir, approximately 80 km from the coast. Due to the absence of suitable local stone in the surrounding area, the amphitheater was built from a mixture of siliceous and calcareous pebbles cemented together with mortar. The amphitheater is ellipsoid, with its long axis oriented from east to west, so the seating terraces, raked at an angle of 40-45° to the horizontal, essentially face either north or south. It is 156.5 m long x 134 m broad, with a 'stage' area measuring 71 x 49 m. Our study was limited to the internal part of the amphitheater, i.e. the ellipsoid ring including the seating terraces.

Relevés, ca. 50 x 50 cm, were undertaken at 37 locations as indicated in Figure 1. Although randomly investigated, some attempt was made to represent the full range of habitats in terms of aspect and height above the arena. In the field, the abundance of each taxon was evaluated according to the cover scale of Braun-Blanquet (1964). No relevés contained vascular plants, and bryophytes and algae, not included in the analyses, provided only very low cover values. It must be noted that the relevés were not strictly phytosociological due to the complicated nature of the substrata, which rendered almost impossible the selection of "homogeneous" surfaces, but they do accurately describe the assemblages of species found in the amphitheater. Field data were subjected to reciprocal ordering ordination and complete linkage clustering, with resemblances measured as Euclidean Distance, using the package of Wildi & Orloci (1984). These analyses made it possible to detect ecological gradients, to define clusters of floristically similar relevés, and to model the lichen distribution on the monument.

The chromatic model was constructed by considering only relevés taken on horizontal surfaces. The species were subdivided into three main colour groups: a) orange-yellow, b) white (including light grey and light green), and c) dark (from dark brown and grey to black). The cover of each group in each relevé was calculated by summing the cover values of all species in each group and attributing to "+" the value of 0.1. The percentage cover of the three colour groups in each relevé were processed by a program of automatic mapping (SURFER, Golden Inc., Colorado) which transforms the originally discrete data structure into a continuous distributional model. This program produced three maps showing the spatial distribution of the three main colours within the amphitheater. Nomenclature follows Nimis (1993).

RESULTS

In all, 77 lichen taxa (all but four determined to the species level) were recorded (Table 1). The classification revealed five main clusters of relevés (Figures 2 and 3, Table 1) with the following characteristics:

Cluster 1 (5 relevés): on south-exposed vertical surfaces (Figure 3); dominated by cyanobacterial lichens, but usually with low cover values.

Cluster 2 (9 relevés): on horizontal surfaces in the south-exposed half of the amphitheater (Figure 3). No differential species, but ecologically optimal for *Aspicilia calcarea*, hence the predominant white colour of this group.

Cluster 3 (8 relevés): on horizontal surfaces near the outer rim of the amphitheater (Figure 3). A mixture of calcicolous and silicicolous species, but ecologically optimal for several nitrophilous lichens such as *Xanthoria mediterranea*, hence the predominant orange colour of this vegetation.

Cluster 4 (9 relevés): on horizontal surfaces in the north-exposed half of the amphitheater (Figure 3). Ecologically optimal for *Verrucaria macrostoma*, *V. nigrescens* and *Aspicilia radiosa*, hence the predominant dark brown-grey colour of this vegetation.

Cluster 5 (6 relevés): on north-facing vertical surfaces (Figure 3). Several endolithic species exclusive to this predominantly light grey coloured group.

In the ordination of the relevés (Figure 4a), the clusters appear in the following sequence along the first axis: 3, 2, 4 and 1 + 5. The first axis separates horizontal (negative scores) from vertical surfaces. The cluster with the most nitrophilous and the highest incidence of silicicolous species has the highest negative scores on the first axis; the cluster with the less nitrophilous species found on vertical surfaces has the highest positive scores; the other three clusters are intermediate. The second axis separates the two extreme environmental situations, namely vertical south-exposed and vertical north-exposed (clusters 1 and 5). This ordination can be interpreted in terms of a complex gradient of one or more of the following three main factors:

1) Acidity of the substratum (i.e. group 3 - higher incidence of silicicolous species - separated from all others on the first axis).

2) Eutrophication (i.e. gradient of this factor along the first axis).

3) Solar radiation (i.e. gradient from vertical north-

TABLE 1
Occurrence and cover values of the species in the relevés (numbered as in Figure 2)

RELEVE GROUP NO.	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
RELEVE NO.	21	19	17	20	2	4	16	22	6	3	7	15	5	1	18	32	31	35	10	34	26	8	14	13	11	9	12	33	23	25	24	37	36	27	28	29	30
Anema sp.	1	3	2	+	+					+																											
Thyrea confusa	+	+	+																																		
Peltula euploca	1	+		+																																	
Peltula obscurans	1	+		+																																	
Peccania coralloides	+		+																																		
Catapyrenium sp.		+				+	2		+	+									+																		
Gonohymenia nigritella	+	+	+	+		+	+			+	+						+		+				+														
Lichinella stipatula	+		+				+	+									+		+				+	+													
Verrucaria fuscula						+	+	+	+		+	+	+	+		+	+																				
Aspicilia calcarea	+				5	5	3	4	5	3	2	5		4	2	+	+			+			+			+			+	1							
Toninia taurica	+			+	+			+	+	+	+		+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+								
Placopyrenium buceckii						+	+	+			+							+		+																	
Caloplaca cf. interfulgens					+		+	+	+	1	1		1	+	+	1		+	+	1		1	+		+												
Rinodinella controversa									+	+	+					1		+		+																	
Caloplaca coronata						+		2	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+		+	1							
Candelariella medians																	+	+		+																	
Endocarpon pusillum											+						+	+	+	+	+		+		+												
Toninia albilabra															+	+		+		+			+								+		2				
Caloplaca inconnexa								+				+		1	+	1		+										+									
Caloplaca aurantia		+		+			+	+	+	+	+	+	+	+	1	1	+		+	+	+	1	+	+	+	+				1				+			+
Diploschistes actinostomus																		+		+																	
Lecanora muralis								+	+	+		+	2	1	1	1	+	+	2	1	+	2	1	1	1	1	+	1				+	+				
Diploschistes diacapsis										+		+	3		+	+	2	2	2	1	1	2	2	1	3		2	+		+		1	+				
Catapyrenium pilosellum																+	+		+	+			+	+		+				+		1	1				
Diplotomma venustum												+		+		+			+				+	+	+												
Xanthoria mediterranea						+	+			+	+				2	2	3	3	2	2	1	2	1	1		1	1										+
Collema cristatum																+		+		+	+																
Verrucaria macrostoma							+							+	+			1	+	1		+	1	2	1	2	2	1	2	1	1						
Diploschistes ocellatus																	+	1	2	2	1											+			+		
Parmelia pulla													+				+	+	1	+	+	+	+	+		+											
Collema cristatum													+		+	+	+	+	+	+	+		+	+	+		+	+	+							+	
Lecanora campestris												+	1		2	+	2	+	1	1	1	1	1	+					+							+	+
Aspicilia radiosa							+		+			+	+	2		1	+	1	1	1	1	+	1	2	2	1	1	3	1	1				1	+		
Squamarina cartilaginea						+	+			+				+	+	+	+		+	+	1	+	1	1	1	3	1	+	+	+	1	1	2	1	+		
Toninia aromatica												+			+	+	+		+		+	+			+	+		+						+			
Verrucaria calciseda																	+		+		+			+		+	1								+		
Fulgensia fulgida																			+						+	+	+					2	+	+			
Squamarina concrescens											+			+				+	+	+			+		+	+		+				1	1	1	1	1	+
Fulgensia subbracteata													+			+				+			+	+	+	+				+		1		+	+	+	+
Caloplaca teicholyta									+	1	+			+					+		+	+				+			+		+			+	+	1	+
Xanthoria calcicola								+									+					+											+	+	+	+	
Clauzadea immersa															+																					+	
Solenopsora cesatii														+																						+	+
Verrucaria glaucina																													1		+					+	+
Diplotomma epipolium																																		+	+		+
Leprocaulon microscopicum																																				+	+
Verrucaria viridula																					1													2	+	1	1
Caloplaca xantholyta																																		+	+	+	+
Caloplaca flavescens																																+			+		+
Verrucaria nigrescens	+	+	+		+	+	+	1	+	+	1	+	+	+	+	+	1	+	1	+	2	1	1	2	2	3	2	2	2	2	3			2	3	2	4
Aspicilia hoffmannii		1	+		1	+	2	+		2	2	+	1	1								2	+	+	+	+	+		1	1	1			+	1	1	1
Caloplaca citrina					+	+					+						+	+		+		+	+		+												
Lecania turicensis					+		+			+			+	+			+		+			+							+								+
Caloplaca holocarpa							+			+	+	+	+	+	1	+	+		+		+	+	+				+		+	+				+			
Psora decipiens										+	+	+	+							+				+		+						2	1				
Rinodina guzzinii							+									+							+				+				+						
Lecanora albescens					+		+				+																							+			+
Verrucaria tectorum							+	+		+				+									2				+		+		+						
Caloplaca lactea										+					+								+				+										
Collema tenax											+												+														+
Aspicilia contorta s. str.					+						1																							+			
Diplotomma murorum										+					+				+																		
Verrucaria lecideoides													+	+													+										
Endocarpon cf. latzelianum																									+				+							+	
Collema polycarpon	+															+																					
Lecanora dispersa										+															+												
Candelariella vitellina									+								+																				
Physconia grisea																				+			+														
Toninia cinereovirens																							+														+
Toninia sedifolia																											+								+		
Squamarina lentigera																									+		1										
Lecidea lurida													+																								
Caloplaca erythrocarpa									+																												
Caloplaca variabilis																		1																			
Caloplaca sp .																	+																				
Psora tabacina																	+																				
Toninia sp .																									+												

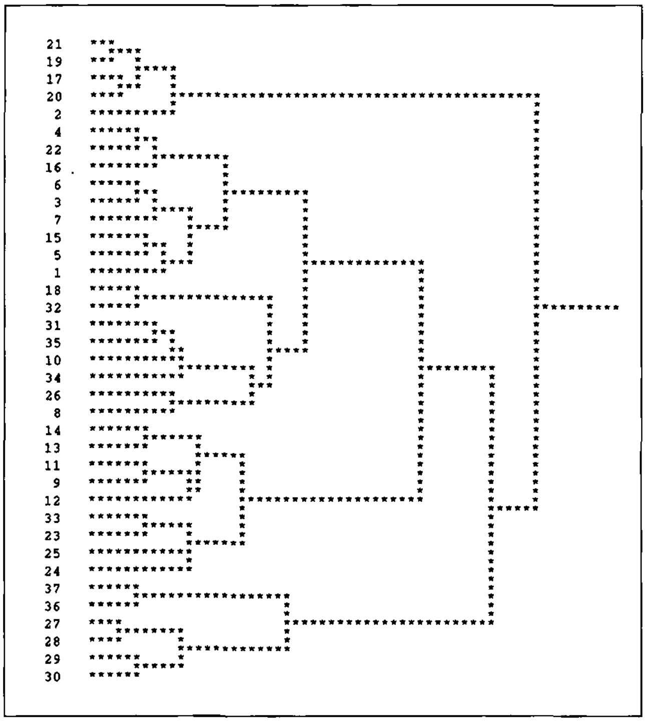

FIGURE 2 - Dendrogram of the relevés, numbered as in Table 1.

exposed to vertical south-exposed along the second axis).

Correspondingly, ordination of the taxa (Figure 4b) shows that both silicicolous (e.g. *Parmelia pulla*, *Lecanora campestris*, *Diploschistes actinostomus*) and highly nitrophilous lichens (e.g. *Candelariella medians*, *Caloplaca coronata*, *Xanthoria mediterranea*) have high negative scores on the first axis; heliotrophic and non-nitrophilous species (e.g. *Aspicilia calcarea*, several *Lichinaceae*) have high negative scores on the second axis, and weakly or non-nitrophilous species (e.g. *Verrucaria viridula*, *Peltula euploca*) have high positive scores on the first axis. The second axis separates heliotrophic species, such as *Peccania coralloides* and *Peltula euploca*, from less heliotrophic ones, such as *Leprocaulon microscopicum* and *Caloplaca xantholyta*.

The above results provide a simple model of the chromatic hue produced by lichens on the stones of the amphitheater: five community-types, characterized by different assemblages of species, and hence by different colours, occur on five structural-ecological units. Vertical surfaces are light-grey coloured when north-exposed (cluster 5), deep black when south-exposed (cluster 1).

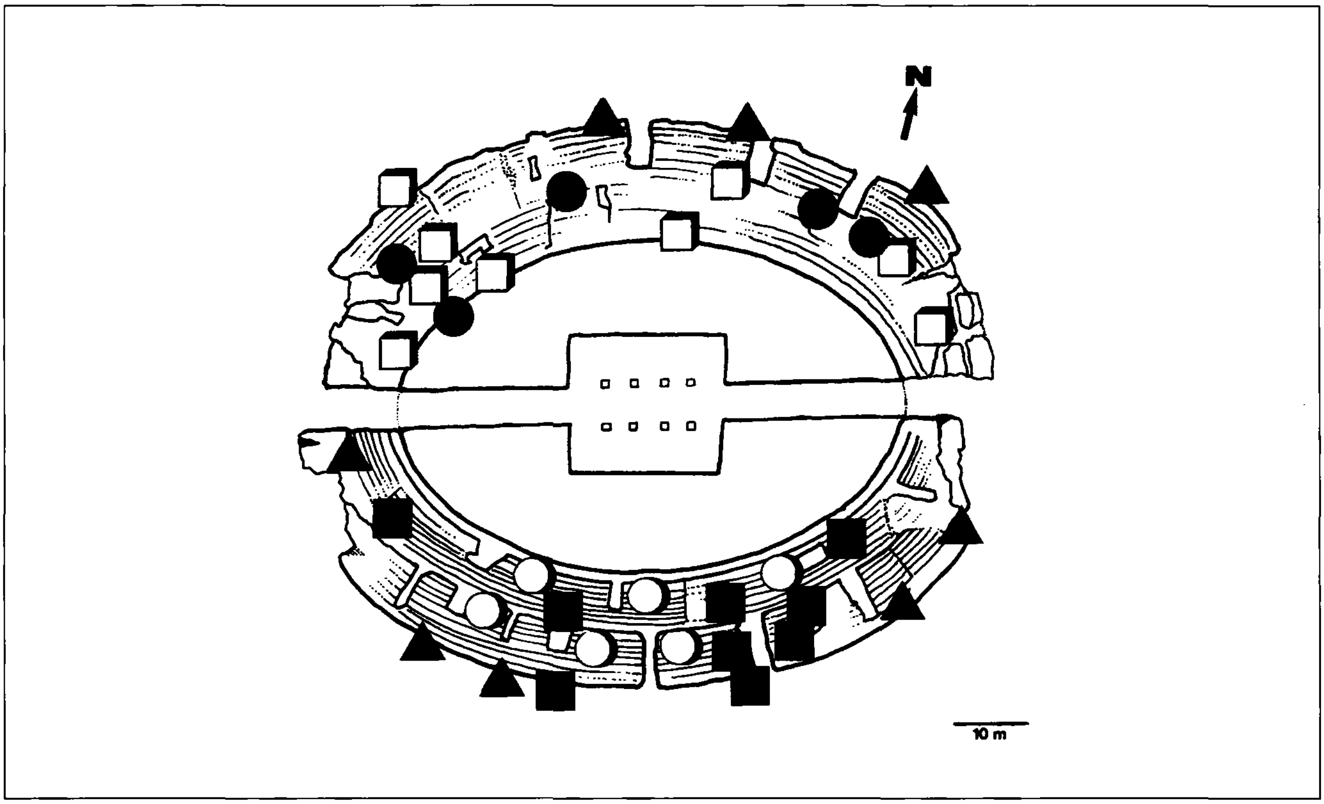

FIGURE 3 - Location of the five main clusters of relevés (see Figure 2) within the amphitheater. Symbols, refer to clusters (see Figure 2, Table 1), as follows: ○ = 1, ■ = 2, ▲ = 3, ❑ = 4, ● = 5.

Figure 4a-b - Reciprocal ordering ordination of the relevés (a) and of the species (b). The clusters of relevés are indicated by symbols, as in the legend to Fig. 3 (Figure 4a). Only species with high absolute scores on the two axes of the ordination are specified (Figure 4b).

The model of lichen-induced chromatic changes on horizontal surfaces is shown in Figure 5a-c: an orange-yellow colour prevails along the outer rim of the amphitheater (Figure 5a), a dark grey-brown colour dominates in the southern, north-exposed half of the amphitheater (Figure 5b), while a light coloration, predominantly white, dominates in the northern, south-exposed half of the amphitheater (Figure 5c).

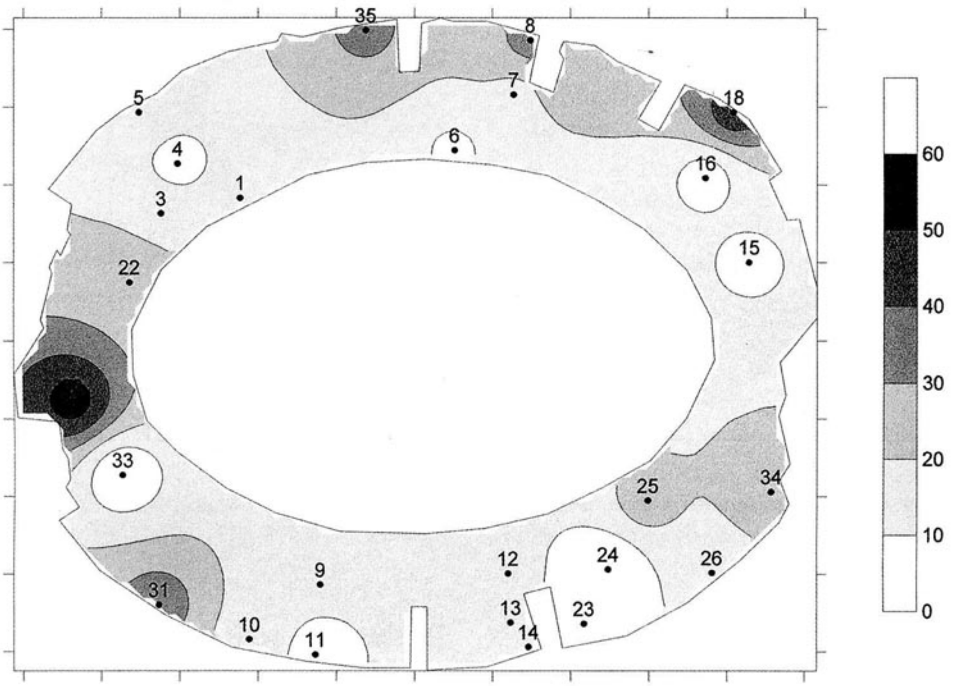

FIGURE 5a - Model of the distributional patterns of three main colours within the amphitheater: yellow-orange.

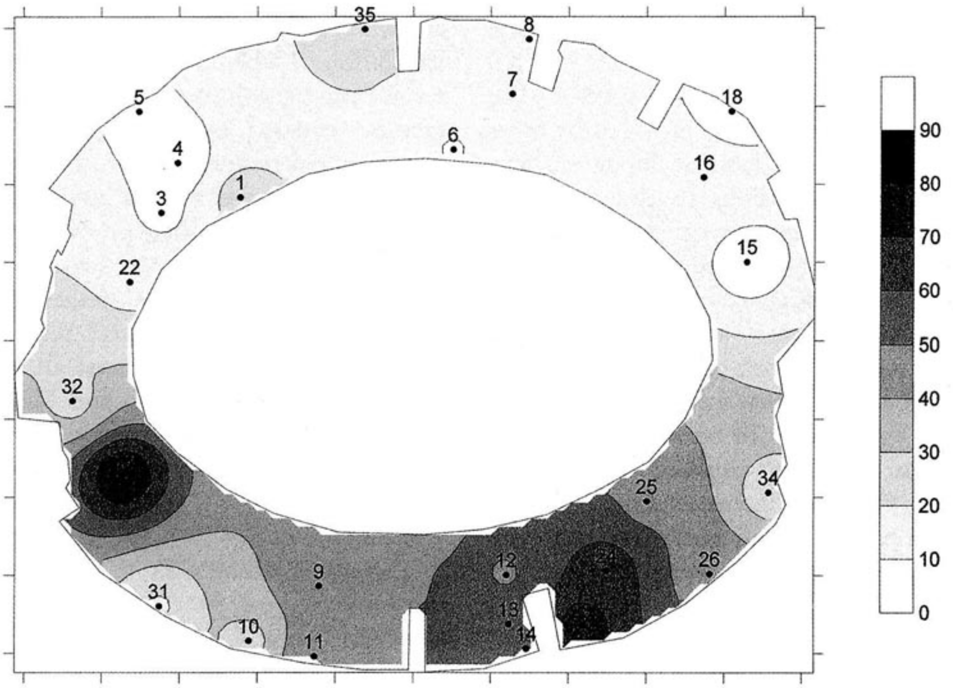

FIGURE 5b - Model of the distributional patterns of three main colours within the amphitheater: dark brown-grey to black.

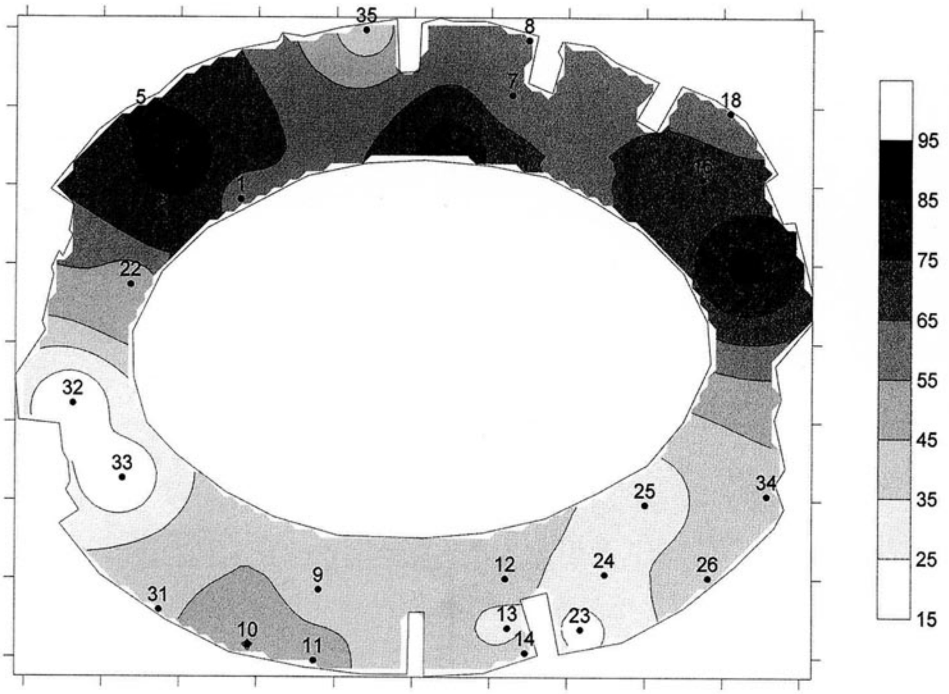

FIGURE 5c - Model of the distributional patterns of three main colours within the amphitheater: white.

DISCUSSION

Three main factors affect the lichen vegetation in the amphitheater: substratum, eutrophication and solar irradiation. The ratio of siliceous to calcareous pebbles on the outer rim of the amphitheater is increased due to the abrasive action of the wind on the softer calcareous component of the building material; this is responsible for the peculiar floristic composition of cluster 3 with a mixture of silicicolous and calcicolous species. The outer rim of the amphitheater is also favoured by birds for perching; the ornithocoprophilous input explains the high incidence of nitrophilous species. Naturally occurring eutrophication is greater on horizontal than vertical surfaces; hence the expected cluster sequence of increasing eutrophication is: 1 + 5 (vertical), 4 + 2 (horizontal within amphitheater), and 3 (horizontal on outer rim of amphitheater), which corresponds with the sequence of clusters along the first axis of the ordination (Figure 4a). Solar irradiation will be much greater on south-exposed than on north-exposed vertical and horizontal surfaces; this factor increases with height, the uppermost terraces of the amphitheater being free from shadow effects. Relevé clusters can therefore be ranked in the following sequence according to increasing potential solar irradiation: 5 (vertical, north-exposed), 4 (horizontal, northern half of the amphitheater), 2 (horizontal, southern half of the amphitheater), 3 (horizontal, outer rim throughout the amphitheater), and 1 (vertical, south-exposed), which corresponds reasonably well with the sequence along the first axis of the ordination (Figure 4a). Essentially, the first axis reflects a gradient of nitrogen enrichment, complicated by the fact that the most nitrophilous community is also that with the highest incidence of silicicolous species, and the second axis reflects a gradient in potential solar irradiation. Lichen-induced chromatic modifications result from the complex interplay of different ecological factors revealed by our analysis, and show clear distributional patterns within the amphitheater's ring. They do not cause serious aesthetic problems in the amphitheater itself. At Italica, however, similar chromatic changes are evident also on statues, columns and bas-reliefs, due to similar assemblages of species as those studied in the amphitheater, responding to similar ecological factors. Since most of these species are widespread on monuments and buildings throughout Central and Southern Europe, our results might be of general interest for those interested in lichen growth on works of art.

ACKNOWLEDGEMENTS

We are grateful to the Director of the Italica archaeological site, Dr J. M. Rodríguez Hidalgo, for his kind permission to carry out fieldwork, and for useful information about the Amphitheater. We are also grateful to N. Valdevit (Trieste) for technical assistance.

REFERENCES

BRAUN-BLANQUET J.J., 1964 - *Pflanzensoziologie. Grundzüge der Vegetationskunde.* 3rd ed., Springer, Wien & New York.

GARCÍA-ROWE J. & SÁIZ-JIMÉNEZ C., 1988 - *Colonization of mosaics by lichens: the case study of Italica (Spain).* Studia Geobot., 8: 65-71.

GARTY J., 1990 - *Influence of epilithic microorganisms on the surface temperature of building walls.* Can. J. Bot., 68: 1349-1353.

JONES D. & WILSON M.J., 1985 - *Chemical activity of lichens on mineral surfaces - a review.* Int. Biodeterioration, 21: 99-104.

NIMIS P.L., 1993 - *The lichens of Italy. An annotated catalogue.* Mus. Reg. Sci. Nat. Torino, Monogr. 12, 897 pp.

NIMIS P.L. & MONTE M., 1988 - *The lichen vegetation on the cathedral of Orvieto (Central Italy).* Studia Geobot., 8: 77-87.

NIMIS P.L., MONTE M. & TRETIACH M., 1987 - *Flora e Vegetazione Lichenica di Aree Archeologiche del Lazio.* Studia Geobot., 7: 3-161.

NIMIS P.L., PINNA D. & SALVADORI O., 1992 - *Licheni e Conservazione dei Monumenti.* Cooperativa Libraria Universitaria Editrice, Bologna.

PUERTAS F., BLANCO-VARELA M. T., PALOMO A., ORTEGA-CALVO J.J., ARIÑO X. & SÁIZ-JIMÉNEZ C., 1993 - *Decay of Roman and repair mortars in mosaics from Italica, Spain.* Sci. Tot. Environ., 153: 123-131.

SEAWARD M. R. D., 1988 - *Lichen damage to ancient monuments: a case study.* Lichenologist, 10: 291-295.

SEAWARD M. R. D., 1996- *Lichens and the environment.* In: SUTTON B.C. (ed.). *A century of mycology*: 293-320. Cambridge University Press, Cambridge.

SYERS J.K. & ISKANDER I.K., 1973 - *Pedogenic significance of lichens.* In: AHMADJIAN V. & HALE M. E., (eds.). *The lichens*: 225-248. Academic Press, New York.

TRETIACH. M. & MONTE M., 1991 - *Un nuovo indice di igrofitismo per i licheni epilitici sviluppato sui nuraghi di granito della Sardegna nord-occidentale.* Webbia, 46, 1: 163-172.

TRETIACH M., MONTE M. & NIMIS P.L., 1991 - *A new hygrophytism index for epilithic lichens developed on basaltic nuraghes in NW Sardinia.* Botanika Chronika, 10: 953-960.

WILDI O. & ORLOCI L., 1984 - *Management and multivariate analysis of vegetation data.* 2nd ed. Swiss Federal Institute of Forestry Research, Birmensdorf.

AUTHORS

Pier L. Nimis (corresponding author), Dipartimento di Biologia, Università di Trieste, Via Giorgieri 10, 34127 Trieste, Italia.

Mark R. D. Seaward, Department of Environmental Science, University of Bradford, Bradford BD7 1DP, UK

Xavier Ariño, Instituto de Recursos Naturales y Agrobiología, C.S.I.C., Apartado 1052, 41080 Sevilla, España

Eva Barreno, Depto. de Biología Vegetal (Botánica), Universidad de Valencia, Dr Moliner 50, E-46071 Burjassot, Valencia, España