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LICHEN-INDUCED BIODETERIORATION OF ITALIAN MONUMENTS, FRESCOES AND OTHER ARCHAEOLOGICAL MATERIALS

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Abstract: An appraisal is made of the part played by lichens in the deterioration of stonework. Stone- and art- work in exposed and partially enclosed environments of Central Italy were examined in detail to identify those substrata most vulnerable to lichen attack. Assessment of relationships between particular species and the physical and chemical nature of their substrata was carried out in order to determine the relative importance of lichens in biodeterioration processes obtaining in specific circumstances, and to establish those species responsible for disfigurement and those causing actual destruction. Particular attention is paid to recent environmental changes conducive to increasing detrimental invasion of terracotta, mortar and painted plaster, and reference is made to examples of building materials, statuary and other ornamental carvings, terracotta pots and frescoes, both those *in situ* at Ostia Antica, Rome and Caprarola (Viterbo) and those relocated in open-air museums, etc.

Introduction

Those concerned with the preservation of monuments view the encroachment of lichens as a disfiguring threat, obscuring inscriptions and fine detail and often causing actual physical deterioration of the stonework itself. Since damage can be brought about by a multitude of both physical and chemical processes, exacerbated in urban environments, as well as through biodeterioration, it is essential to determine that damage to any particular monument is indeed attributable to lichen action, especially since cleaning techniques may well accelerate deterioration.

These problems are particularly evident in those countries such as Italy where ancient cities are exceptionally rich in fine historical monuments of international importance. The problems are under-researched, due to the lack of interdisciplinary co-operation, and much of the published work is of a largely empirical nature. Collaborative research between the Department of Microbiology of the Institute for Restoration in Rome and the School of Environmental Science at Bradford University has been undertaken since 1982 (e.g. Giacobini *et al.* 1986), but not until four years later was the opportunity afforded for the respective researchers to actually work together on site.

The role of lichens in the biodeterioration of stonework

Undoubtedly some lichen species do contribute to the deterioration of a wide range of building materials. Biodeterioration of stonework can be the result of either physical or chemical processes. Modern electron microscopy and chemical tecniques have made it possible to recognise that lichens are implicated in both these processes. In the past, attention was drawn to the possible effect of dissolved carbon dioxide, derived from lichen respiration, attacking the substratum to produce pits and channels for easier penetration of hyphae, with attendant loosening of mineral particles and their incorporation into lichen tissue. Such effects, although important on a geological time-scale, have so far been considered to be minimal in terms of the life of ancient monuments. However, it would appear from observations made during the course of this study that many lichen species create microclimatic effects at the thallus/substratum interface, particularly in terms of water retention, which undoubtedly lead to mechanical damage to stonework on a short time-scale of ten, or even fewer, years. Various crustose and squamulose lichens are implicated, their aggressive behaviour no doubt promoted by particular man-made environmental conditions. Furthermore, forces generated by climatic wetting and drying of the lichen thallus cause it to expand and contract, which in turn mechanically disrupts the substratum. Taken in conjunction with the chemical breakdown of substrata by lichen acids, etc., it is clear that all these biogeophysical processes will assume greater importance.

Lichen acids have a relatively low solubility, but they are effective chelators, forming metal complexes with silicates, etc., derived from the substratum. X-ray powder diffraction and transmission electron microscopy have clearly demonstrated the presence of characteristic alteration products at the interface between rocks and various lichens. Experiments involving pure lichen acids or lichen fragments incubated with different types of rock have confirmed these observations. Many lichens known to contain calcium oxalate cause extensive corrosion of a range of rock substrata. Oxalic acid secreted by the mycobiont is extremely soluble in water and acts as a chelator of metal ions, and oxalates formed at the thallus/substratum interface are closely related to the chemical composition of the rock; thus, species growing on serpentinite, mainly composed of magnesium silicate, form magnesium oxalate dihydrate at the interface.

The report by Del Monte and Sabbioni (1987) of the occurrence of oxalates and lichen fragments in *scialbatura,* the patina of exposed marble monuments, etc., is of particular interest in this context and warrants further investigation, as do the findings of Krumbein and Schönborn-Krumbein (1987) regarding the role played by lichens in specific types of pitting of ancient stonework; however, the nature of the penetrations appears to be uncharacteristic of previously observed lichen action. It is possible that lichens have initiated a chain of reactions resulting in such deterioration, but the precise extent of their involvement, particularly in respect of the time-scale, needs clarification.

There is, therefore, strong reason to believe that lichen acids, oxalic acid and other organic acids are all involved in the biodeterioration of stonework, etc., and that some mechanical processes may be interacting with these chemical processes (Jones & Wilson 1985).

Study sites

Detailed investigations were made at the following sites:
(1) Villa Madama, Rome - house, and gardens (statues, walls, pavements and sarcophagus).
(2) Tombe Latine, Rome - above-ground calcareous and siliceous stonework, and shaded subterranean walls.
(3) St. Stephen's Basilica, Rome - walls and fallen columns.
(4) Museo Nazionale Romano - outdoor monuments made of a variety of stonework, and terracotta pots.
(5) Palazzo Farnese, Caprarola - wall frescoes on ground and first floor cloisters facing onto inner courtyard, and garden monuments and walls.
(6) Ostia Antica - buildings, pavements and monuments in a variety of stonework, and *in situ* terracotta storage pots.

In addition, numerous other archaeological sites (e.g. Palatine and Capitoline Hills, Trajan's Forum), monuments, churches, etc. in Rome were visited, and their lichen floras noted (Seaward 1987). Comparisons were also made with the impoverished urban flora generally to be found in, and near to, Rome.

Results

(1) Villa Madama

The walls of the villa had scattered colonies of lichens, mainly *Dirina massiliensis* forma *sorediata*, but no species of particular interest; no problems of biodeterioration caused by lichen growth were noted. A neoclassical statue, near to the villa, was, however, clearly suffering from disfigurement, the main cause of which was due to algal growth creating, in particular, a dark rust-brown colouration of the face. Several lichens were detected as secondary colonizers to the alga, with small thalli of *D. massiliensis* forma *sorediata* becoming established in niches created, for example, by folds in the dress. Cleaning of such statuary should be undertaken before secondary colonizers have time to establish themselves. The plinth to this statue was more densely colonized by lichens, a few species, including *Leproplaca chrysodeta*, being suited to the drier, and sometimes shady crevices.

The lichen flora of the granitic columns in the garden walk contrasted sharply with that of the calcareous columns, the former being very poorly colonized, the only notable feature being a few thalli of the foliose *Parmelia glabratula* ssp. *fuliginosa*.

The calcareous columns, on the other hand, supported both foliose (e.g. *Physconia grisea*, *Physcia adscendens*, *Xanthoria parietina*) and crustose species (mainly *Caloplaca* ssp. and *Verrucaria nigrescens*), several columns having large areas dominated by *Scoliciosporum umbrinum;* calcareous plinths to granitic columns had a similar flora.

An archaeologically important sarcophagus gave cause for concern: almost the entire surface of the three exposed faces was covered with lichens, mainly *Protoblastenia rupestris,* and algae, the only uncolonized areas being near to water spouts where the action of running water and presence of lead inhibited growth. The removal of this monument to a covered area is recommended.

Garden ornaments, such as seats, statues and their plinths, walls and pavements, being mainly of calcareous material, supported a diverse and often colourful lichen flora, the wall capstones in particular providing a pleasing mosaic of about 18 species, none of which appeared to be acting detrimentally. Unused areas of pavements were covered with lichens, occasionally *Collema crispum,* and the junction between the bowl of an urn and its base created a favourable habitat for *C. tenax* and secondary colonization by bryophytes.

(2) Tombe Latine

An avenue of interesting fragments of Roman buildings including short stretches of calcareous and siliceous (tufa) walls, together with isolated 'monoliths', supported rich lichen floras, often with a number of nitrophilous species (no doubt as a result of the application of agrochemicals in neighbouring gardens). Tufa walls were particularly colourful with at least 20 species, including *Caloplaca festiva, Candelariella coralliza, Lecanora muralis, Parmelia verruculifera, Xanthoria calcicola* and *X. parietina.* Walls constructed from a mixture of calcareous and non-calcareous stones, or siliceous stonework heavily pointed with cement, obviously created 'anomalous' mixed floras of such species as *Aspicilia calcarea* var. *reagens, Caloplaca aurantia, Lecidea fuscoatra, Lecanora campestris* and *Acarospora fuscata.* Wholly calcareous walls supported mainly crustose species, particularly *Lecanora pruinosa,* and occasionally *Physcia adscendens* and *Phaeophyscia orbicularis.* The shaded subterranean walls forming part of the Tomb of the Valeri were covered with *Lepraria incana,* scattered throughout with *Opegrapha mougeotii.*

(3) St Stephen's Basilica

Due to major reconstruction work, a sparse and species-poor calcareous flora, similar to that described at site 2 above, was encountered.

(4) Museo Nazionale Romano

A grassed area surrounded by cloistered museum buildings contained numerous archaeologically important monuments and artifacts constructed from a variety of materials. In interpreting the deterioration of these materials, the ambient urban climate (and associated atmospheric pollutants) should be taken into consideration, particularly since the latter dramatically affects the lichen flora: it was noted, for example, that several of the more toxi-tolerant species (poleophiles) with an aggressive behaviour were actively colonizing stonework, etc.

The funerary monument to the Fontei has been reconstructed from a variety of materials: the juxtaposition of calcareous and non-calcareous materials, particularly the use of heavy cement pointing over acidic stonework, has resulted in lichen colonization of the alkaline substrata in the first instance through the ability of the latter to buffer low pH pollutants derived from the atmosphere; from such colonization points, several species had spread onto more important areas of the monument. No ''damp-course'' was observed between the monument and the ground on which it stood, and there was strong evidence that fertilizers and/or other chemicals had been used to treat the surrounding lawn in view of the presence of nitrophilous lichen species on the stonework, particularly near the base. The front of the monument had a relatively rich lichen flora, some species such as *Acarospora umbilicata* and *Lecidea fuscoatra* being obviously responsible for the deterioration on the right-hand side. The shaded back face also supported several species, including *Acarospora umbilicata, Buellia punctata* and *Scoliciosporum umbrinum.* Many of the disfigurement problems of this monument arose from an unsympathic use of materials for its reconstruction in the past. A similar case was observed in respect of a statue of a horse's head which had been mounted on a concrete neck, the latter providing the initial focus for unsightly lichen colonization.

The most dramatic and alarming case of lichen attack was observed in the case of several large terracotta pots scattered about the lawn. The rims and shoulders of these pots were lightly colonized by such innocuous species as *Lecanora dispersa* and *Candelariella vitellina,* with occasional thalli of *Acarospora umbilicata* and *Lecidea fuscoatra,* but here and there, thalli of *Lecanora muralis,* mainly 4-7 cm in diameter, probably representing less than 8, and no more than 15, years' growth, were causing demonstrable damage (Seaward 1988). A section through one of the thalli clearly reveals the results of such damage: a central blister, created by the crowding of apothecia, pulled away a fragment of the substratum two or more millimetres in thickness, over an area almost 12 cm^2. Re-examination of the terracotta pots in 1988 revealed several occurrences of identical surface blistering and subsequent flaking induced by *L. muralis,* thus substatiating the interpretation made two years earlier. *L. muralis* appears to be a highly successful lichen in urban environments into which it has spread dramatically, due in part to lack of competition from other species, over the past few years (Seaward 1982); a change in the nature of air pollution in Rome in that period may be a contributory factor to this aggressive behaviour.

(5) Palazzo Farnese

This beautiful mansion on a hillside, built by Vignola in 1547-49, features a circular courtyard surrounded by cloisters on ground and first floor levels, the inner walls of which bear frescoes by Zuccari painted in the 1560s. The water-based paintwork has shown signs of biodeterioration in recent years; examination revealed that one lichen species, *Dirina massiliensis* forma *sorediata,* is responsible for the disfigurement. The latter gives great cause for concern, the attack being very pronounced in many places, showing the predilection of this lichen for the brown and yellow pigments, rather than the red pigment which probably contains a metal antagonistic to its growth. The distribution pattern of this lichen is not only dictated by the colour of the paintwork: when viewed at several paces distant from the frescoes, it is obvious that some cleaning activity (probably of recent occurrence in view of the small size and discreteness of the lichen thalli) has distributed lichen propagules from an innoculum, or dispersed them from existing thalli, to create distinctive areas of lichen invasion which arc across the frescoes.

Lichens are now being painstakingly removed from the frescoes by means of a scalpel; since each thallus removed takes with it the colour from beneath, it is necessary to meticulously repaint each area so exposed. This is labour-intensive, taking many weeks to cover just a few square metres. The use of liquid chemicals to control the lichen is out of the question in view of the water-based nature of the paint; perhaps a gas could be used, but those known to kill lichens would also be detrimental to the frescoes.

(6) Ostia Antica

This magnificent site is rich not only archeologically but also lichenologically: tufo, travertino and brick building materials all provide ideal substrata for crustose and foliose species; brick and plasterwork also support the fruticose *Roccella phycopsis,* a maritime lichen more commonly found on rocky shores, particularly on the back wall of the Capitolium where it densely clothes the brickwork in association with *Dirina massiliensis* s.str.; *Roccella phycopsis* is also found on inner walls of houses, where it is clearly damaging frescoes, and occasionally elsewhere. The frescoes in the houses along Via Diana were also colonized by at least six crustose species which were naturally causing disfigurement: suitable protection for these frescoes is a prerequisite for their conservation.

The walls in and around Porta Laurentina were investigated in some considerable detail, especially since some of the characteristic walling, constructed of small tufa blocks, heavily mortared together, is in poor condition, largely due to vascular plant action (particularly by *Hedera helix).* However, since lichens are undoubtedly the precursors to colonization by higher plants, consideration should be given to their role in the deterioration process; *Toninia aromatica* appears to be important in this respect. In all approximately 30 lichen species were identified from the stonework of the gateway and adjacent walls: they did not appear to be contributing significantly to the deterioration of the travertine blocks, but this should be monitored in view of the archaeological importance attached to the latter.

Some attention was also given to the Forum: much of this had been restored (and reconstructed). It was interesting to compare the lichen flora on the reconstructed parts with that on fallen masonry. The bases of the columns were almost completely colonized by calcareous lichens (mainly *Caloplaca* spp.), but the columns themselves were devoid of lichens with the exception of the mortarwork used in the reconstruction. The reconstructed pavements, where untrodden, supported a flora composed mainly of *Aspicilia calcarea, Caloplaca citrina, C. aurantia* and *Lecanora pruinosa;* the differences, often only subtle, between floras of original and reconstructed stonework can be detected in the field, but more quantifiable data are necessary before a technique based on recognizing these differences could be employed, for example, in relative dating.

In situ terracotta storage pots, sunk into the ground to their shoulders, gave cause for concern: they were unquestionably deteriorating, mainly due to the action of crustose and squamulose lichens operating in a manner similar to that described at site 4 above. The 25 cm of neck of each pot appearing above ground level was heavily colonized by lichens, but there was a considerable variation in the flora from pot to pot, indicating differences in the composition of the terracotta; those bearing *Lecanora atra,* for example, were quite obviously blistering, the crumbling lichens falling away with attached substratum, 2-3 mm in thickness, the crowding of apothecia acting in a manner similar to that previously described for *Lecanora muralis.*

(7) Isola Sacra

Attention here was mainly directed towards a comparison of the lichen floras of treated and untreated terracotta panels of cappuccine tombs. All panels (50 cm high) supported a limited flora consisting of small colonies, widely spaced, of *Lecanora pruinosa* and *Diplotomma epipolium,* with occasional thalli of *Caloplaca aurantia;* the effectiveness of chemical treatment, in terms of lichen removal, was inconclusive. A large sarcophagus was also examined: the flora was species-poor, and those lichens present were almost entirely influenced by the considerable quantities of cement used in its reconstruction. The other buildings of the necropolis warrant further lichenological investigation in view of their archaeological importance.

Concluding remarks

The above work, based on field observations in Central Italy, constitutes the necessary first phase of any long-term research programme aimed at quantifying the actual role played by lichens in the deterioration of a wide range of archaeological materials. Stone- and art-work in exposed and partially-enclosed situations, giving rise to a variety of environmental conditions, have been examined in detail in order to identify the relationships between particular lichen species and the physical and chemical nature of their substrata and to determine the relative importance of those species in biodeterioration processes obtaining in specific circumstances. It is necessary to determine, for example, which species are disfiguring but intrinsically harmless, and which cause actual physical damage. This work has produced strong evidence to suggest that recent environmental changes have been conducive to increasing detrimental invasion by certain aggressive lichen species. Such evidence would help to explain why it is that monuments, undamaged for many centuries, appear to be vulnerable to lichen attack, in addition to the known problems resulting from air pollution, in recent years.

It is self-evident that such base-line work is a prerequisite to (1) laboratory research designed to establish the nature of the interface between problematic lichens and their substrata, and (2) field trials intended to test the relative effectiveness of differing techniques and treatments for the removal and discouragement of lichens from stonework. Any treatment should be selected with care, since although immediately effective, the long-term effects may well be deleterious (Richardson 1973). Mechanical methods involving scraping and brushing, usually followed by washing, are tedious, damaging and often ineffective. Absorbed water may adversely affect the monument, particularly under fluctuating temperature regimes; penetration can be minimised by the use of water repellants, but entrapped water and rising damp can prove highly destructive. A wide range of biocides have been employed, many of which have since been rejected due to side-effects such as crystallization of soluble salts which have penetrated the stonework, staining and discolouration of monuments where the chemicals used have interacted with particular metals present in the substratum, and the promotion of secondary biological growths, which may be even more unsightly than the primary growths. Futhermore, regular treatments are likely to be necessary which are expensive both in terms of the chemicals used and the labour employed for the mechanical removal of only partially detached and brittle lichen growths which remain. The biocides employed may also be harmful to the operators and, not surprisingly, dangerous to wildlife. Some success has been achieved using organometallic compounds, quaternary ammonium compounds and borates, but the latter have proved problematic when used in air-polluted environments where, of course, many of the monuments it is desired to conserve are to be located.

The subtle colouration of a varied lichen mosaic can have aesthetic appeal, providing it does not produce disfigurement or unduly obscure detail, and it may also afford a protective barrier, shielding the stonework from external weathering agents. Furthermore, the different lichen communities established on monuments not only reflect the various materials employed in their construction but also can often be correlated to the chronology of successive building phases, therefore assisting in archaeological interpretation.

In the light of the above, any decision to remove lichens from stonework must not be undertaken over-hastily or without very careful consideration of the wider implications and long-term effects. Unfortunately, it has to be acknowledged that the problem is under-researched and much of the work published to date is of a largely empirical nature which has yet to be adequately substantiated by long-term experimentation. It remains for future generations to judge the relative effectiveness of the various conservation techniques currently employed.

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