12th International Congress on the Deterioration and Conservation of Stone
Columbia University, New York, 2012

GREENING STONE CONSERVATION: EXPLORING THE PROTECTIVE ROLE OF PLANTS AND MICROBES

Heather Viles[1]

[1] *School of Geography and the Environment, University of Oxford, England.*

Abstract

Whilst the biodeteriorative roles of some plants and microbial communities have been explored in a range of different environments, much less research has focused on the positive contributions such organisms might make to stone conservation. Climatic change and improving air quality may both encourage biological growths on stone. Three types of role can be identified, i.e. passive modification of microclimatic conditions, active remediation of surfaces, and aesthetic enhancements. Using three case studies from research in the UK I provide a critical examination of these roles in different settings and evaluate their strengths in relation to any biodeteriorative effects. Detailed investigations into the growth of ivy on historic stone walls illustrate that it can have beneficial effects on wall microclimates, thereby moderating conditions and reducing the risks from other processes of deterioration. On the other hand, ivy roots can be highly invasive and damaging when allowed to penetrate into pre-existing cracks and holes. Soft capping of ruined wall tops is shown to modify the environment at the wall head, and reduce the threat of frost damage, whilst any chemical impacts on the underlying stone seem to be minimal. Mixed biofilms dominated by green algae growing on sandstone walls are found to have a complex influence on moisture regimes at the surface, with some evidence of protective effects. Further understanding of the positive and negative roles of different biological growths on historic stone walls is vital for a balanced assessment of risk and more successful conservation in today's changing world.

Keywords: soft capping, biodeterioration, bioprotection, green algal biofilms, ivy

1. Introduction – plants and microbes in relation to stone conservation

Over time in the natural environment microbes and plants will colonise most stone surfaces, unless their growth is actively inhibited. Whilst a profusion of organic growths on stonework has often been seen in the past as picturesque and beautiful, especially in the context of ruins, the dominant viewpoint in modern, international stone conservation has been that biology poses a threat and should be removed where possible. For many decades urban air pollution has limited biological growths on much valuable external stonework, but recent air quality improvements and climate change are likely to enhance plant and microbial growth in many places (Smith et al. 2010; Viles and Cutler 2012). The global economic downturn is also likely to reduce expenditure on both stone conservation and the management of organic growths, and drive the search for cheaper and more ecologically-friendly preventive conservation methods. Within these contexts, there is an urgent need for a more balanced assessment of the role of plants and microbes in the deterioration and conservation of stone.

The impacts of plants and microbes on building stone can be divided into two categories (see Table 1), i.e. biodeterioration and bioprotection. Within both categories we can identify three different types of impact. Firstly, there are important ways in which plants and microbes can actively cause change to stone surface properties, both in the form of deterioration and in the form of remediation. Bioremediation involves the use of biological agents (mainly microbes) and processes to repair or consolidate deteriorated stonework (see, for example, Rodriguez-Navarro et al. 2003; Jimenez-Lopez et al. 2008). Secondly, plants and microbes can also have passive impacts on stone surfaces, simply through covering the stone and altering the microclimatic conditions. These impacts can be seen as positive where they reduce the likelihood of deterioration, or negative where they enhance the rate of deterioration. Thirdly, plants and microbial growths can have an aesthetic impact on surfaces, either improving or reducing the visual appeal of the stonework. For example, there are many arguments about the aesthetic role of lichen communities growing on gravestones, with some authors contending that they enhance the visual appeal, and others seeing them as wholly negative. In reality, of course, mixed plant and microbial communities will have a range of positive and negative impacts, and there will be some overlap between the active and passive roles. Importantly, there is still a lack of knowledge about many of these roles, and thus it is difficult to weigh up positive and negative aspects of biological growths on stonework.

Plants and microbial communities are often seen to cause deterioration of building stone surfaces, through a range of physical and chemical processes. Many studies have been carried out on the nature and importance of biodeterioration of stone, as reviewed in full by Caneva et al. (2008). Some organisms have been found to be particularly deteriorating in their own right (e.g. the lichen *Dirina massiliensis* forma *sorediata*, noted by Seaward, 1997) whilst others have been noted to work synergistically with other deterioration process (e.g. microbial communities and physical weathering as observed by Papida et al. (2000), and fungi and small arthropods as joint agents of biodeterioration of wall paintings as studied by Gorbushina and Petersen (2000). Caneva et al. (2008) illustrate how the nature and rate of biodeterioration of stone varies depending on climatic and environmental conditions, as species and communities and their ecological processes vary, and Viles and Cutler (2012) make some predictions of future trends as a result of 21st century climate change.

Table 1. Potential modes of biodeterioration and bioprotection

Biodeterioration		Bioprotection	
Active	Biologically-mediated chemical and physical processes which deteriorate stone, e.g. endolith boring	Active	Biologically-mediated processes which remediate stone, e.g. bacterial cementation
Passive	Transformation of local environment by biological growths which enhances deterioration, e.g. mosses might increase surface wetness and thus enhance chemical weathering	Passive	Transformation of local environment by biological growths which retards deterioration, e.g. mosses might reduce subsurface wetness and thus decrease chemical weathering
Aesthetic	Cover of biological community reduces the aesthetic appeal of a stone building or object	Aesthetic	Cover of biological community enhances the aesthetic appeal of a stone building or object

Disturbance of ecological communities growing on stone by human activities can produce accelerated biodeterioration, as noted by Warscheid and Leisen (2009) at Angkor Wat. Here, application of biocide was followed by the rapid development of bacterial and algal dominated biofilms causing flaking and delamination. Bioprotection can be defined as the largely passive ways in which microbial biofilms and plant growth modify conditions at the stone surface to prevent or retard deterioration. For example, Carter and Viles (2005) illustrated how many lichen species have a net protective impact on stone surfaces, through the amelioration of temperature and humidity regimes and through physically holding the stone surface together. Arino et al. (1995) note similar bioprotective impacts of lichens on Roman pavements, as do Warscheid and Leisen (2009) at Angkor Wat. However, such bioprotective impacts may only last until the lichen dies. Bioprotection can also involve soil and vegetation systems (either in the form of capping on wall heads, or as complete reburial of ruins and archaeological sites) and plants growing near (rather than on) stone walls, which can provide shelter and amelioration of near-surface microenvironmental conditions.

Much less research has been carried out on bioprotection than biodeterioration, and there have been few attempts to provide a balanced assessment of the impact of biological communities. The three case studies below illustrate some methodological approaches to evaluating different combinations of deteriorative and protective impacts involving a number of different communities of plants and microbes.

2. Case Studies

2.1 Ivy on walls

The role of ivy (*Hedera helix*) growing on walls is a controversial topic, with many entrenched opinions over whether it is positive or (more commonly) negative. Caneva and Roccardi (1991), for example, note *Hedera helix* to be an important agent of biodeterioration on Roman monuments (alongside *Ficus carica* and *Capparis spinosa*) because of its growth and root network characteristics. English Heritage recently commissioned a detailed assessment of the potential benefits of ivy growth. From surveys of a range of historic walls with ivy growths, two particular bioprotective roles have been identified, i.e. the moderation of temperature and relative humidity regimes at the stone surface reducing the threat of physical weathering, and the interception of damaging particulate pollutants reducing the threat of chemical weathering (Sternberg et al. 2010, 2011). Furthermore, no evidence was found that aerial rootlets caused significant deterioration of limestone (Viles et al. 2011). However, as Viles et al. (2011) acknowledge, ivy can root into voids and crevices in and under stone walls under certain conditions, causing problems as the roots grow and exert stresses on the surrounding stone.

One of the problems faced by attempts to identify the exact roles of ivy, and thus in evaluating whether it has net bioprotective or biodeteriorative capabilities, is knowing how deteriorated the stonework was before the ivy grew. It is also difficult to find circumstances where objective comparisons can be made between ivy-covered and bare walls, which are identical in all other aspects. These problems can be circumvented through the use of specially constructed test walls. However, such studies require enough time for ivy to become established and climb up the wall. As part of the English Heritage-funded research, a wall was built in August 2007 in Wytham Woods, near Oxford in England. Constructed of Elm Park limestone with lime mortar joints, the wall consists of 4 faces (1.2 m wide and 2 m high) facing N, S, E and W around a central core. Each face had a series of defects and voids built into it, to encourage ivy roots and shoots to grow into the wall. After almost 5 years the ivy is now well-established, and provides many opportunities to observe contact between aerial rootlets and 'real' roots and the stonework (see Figure 1).

Figure 1. Ivy shoots exploiting defects in test wall, Wytham Woods, near Oxford, UK.

2.2 Soft wall capping

The role of plants growing on ruined wall heads is another controversial topic, with much discussion as to whether they provide protection for the underlying stonework or accelerate decay. Under natural conditions, over time a range of species will colonise and grow on horizontal and near-horizontal wall heads, with a succession of different species growing as conditions change (for example, as a bigger supply of nutrients builds up). Much interest has been expressed in mimicking these natural caps (called soft capping) by emplacing soil and vegetation on ruined wall heads (Wood 2005). Such soft capping may provide a cost-effective and efficient method of preventive conservation, in comparison with the widely used technique of hard capping (finishing deteriorated wall heads with stone and mortar). The potential protective roles of such plant communities involve both regulation of thermal regimes at the wall head, and also the interception and uptake of rainwater. Initial studies commissioned by English Heritage, based on monitoring experimental cappings on ruined walls at a range of sites in England, found turf-based soft capping to be a highly effective thermal blanket, but were not able to conclusively identify beneficial impacts on moisture regimes (Lee et al. 2009). However, negative impacts of soft capping cannot be entirely ruled out. Any woody species may cause deterioration through the action of roots growing into the wall, and there is also the possibility that rainwater may become acidified by contact with the vegetation and then become released into the wall.

Testing the multiple hypotheses of soft capping's positive and negative impacts is difficult. On real ruined walls with soft capping, which has established naturally or by human actions, it is difficult to make objective comparisons between soft capped and non-soft capped or hard capped areas as the nature of ruined walls is very variable, and the deterioration status often unknown (Sass and Viles 2006). As with ivy, a good solution is to build specially designed test walls (some with soft capping and some with hard capping), and monitor thermal and moisture regimes and the rate and nature of deterioration. Four such test walls have been built in Wytham Woods, near Oxford, from Cotswold limestone and lime mortar joints (Figure 2). Each wall consists of a rubble core with dressed stone faces. The walls were built and capped in 2007, and have been monitored ever since. Hard capping was created using stone and lime mortar. The soft capping trialed consisted of around 5 cm of screened loam soil, with turf cut from surrounding grassland. In 2011, small plugs of sedum were added to the edges of the turf capping, as harsh environmental conditions had led to some dieback and erosion of the turf. Sedums are known to be able to survive under dry conditions.

Figure 2. Soft and hard capped test walls, with gutters and down pipes to collect runoff, Wytham Woods, near Oxford, UK.

Over a 3-year period, comparative observations have been made of the moisture regimes on and within the hard capped and soft capped test walls, using a range of methods including hand-held moisture meter surveys, wooden dowels, 2D resistivity, instrumentation with gutters and down-pipes to collect runoff, and time-lapse photography. Surprisingly complex moisture regimes have been observed.

2.3 Green algal biofilms

In recent years enhanced greening of sandstone walls, as a result of green algal biofilms, has been observed in several parts of NW England, as well as Scotland and Northern Ireland. The causes are thought to be the combined impacts of air quality improvements and wetter winters. What is not clear is whether such enhanced algal greening poses a problem for sandstone conservation, or whether it might form a beneficial 'patina'. Increased algal growth may be hypothesized to encourage moisture retention at the stone surface, thereby encouraging deterioration. Alternatively, algal biofilms may produce an almost impermeable barrier on the surface, preventing moisture ingress (but also potentially, preventing moisture escaping from the deeper subsurface zone). Green algal biofilms may also have direct chemical weathering impacts on stonework, through production of organic acids (Cutler and Viles 2011). Quantifying and weighing up these different hypothesized impacts is difficult.

An EPSRC-funded research project has focused on evaluating the roles of green algal biofilms on the deterioration of sandstone, using field monitoring on urban walls in Belfast which are experiencing patchy greening. Alongside this, longer-term studies of a purpose built test wall at Derrygonnelly in western Northern Ireland are in progress (although hampered by the slow development of greening). On four buildings within Belfast detailed surveys have been made of the internal and surface moisture regimes, greening and weathering status along vertical transects of around 2m in height (Figure 3). Using 2D resistivity surveys to probe the moisture regimes, in combination with experimental wetting, we have found no evidence that green algal covered areas are wetter than bare sandstone patches. Indeed, there is evidence that green algal covered patches have a drier subsurface zone, and furthermore that they repel driving rain.

Figure 3. Monitoring moisture uptake on sandstone wall patchily covered with green algae using 2D resistivity surveys, Belfast, Northern Ireland.

3. Discussion

The three case studies presented above indicate a plethora of interactions between plants and microbial communities and stonework. Table 2 synthesizes some of the main findings drawn from these studies. Ivy, whilst having a deservedly bad reputation for causing deterioration through root growth under some circumstances, has been shown from monitoring historic walls and test walls to have many bioprotective abilities. However, it can also shroud historic stonework rendering any important historical and archaeological details invisible. Soft capping has been found to mimic natural colonization and, on balance, promises to be an effective solution to the deterioration of wall heads in many conditions based on studies on ruined walls and test walls. However, it must be vigilantly managed to ensure that woody species are not allowed to colonise, and different plant species may be more effective than grass in some climatic conditions.

Table 2. Modes of biodeterioration and bioprotection found in field-based studies of ivy, soft capping and green algal biofilms. **Bold =** demonstrated impact, *italics* = potential impacts under further study.

	Biodeterioration		Bioprotection	
Ivy on walls	Active	**Root action**	Active	
	Passive		Passive	**Thermal blanket, moisture shield, particulate filter**
	Aesthetic	Covers up detail	Aesthetic	Can look attractive
Soft wall capping	Active	*Enhanced chemical weathering?*	Active	
	Passive		Passive	**Thermal blanket,** *moisture sponge/ shedding*
	Aesthetic	Can look unkempt	Aesthetic	Can look attractive
Green algal biofilms	Active	*Enhanced chemical weathering?*	Active	*Enhanced surface hardening?*
	Passive		Passive	**Moisture uptake/ barrier**
	Aesthetic	Can look unkempt	Aesthetic	

Aesthetically, soft capping has many supporters, although it can be perceived as giving an unkempt and neglected air to a monument. Finally, green algal biofilms have not been shown to cause any harmful environmental modification to sandstone surfaces from surveys in Belfast, but longer-term studies on monitored test walls are needed to evaluate whether their role is positive (or negligible), and whether they are also involved in active deterioration.

4. Conclusions

The case studies reviewed in this paper illustrate the value of integrated monitoring of the impacts of a number of species on historic walls and test walls. Such monitoring projects are often time-consuming, as plants and microbes take time to become established and their impacts may vary from season to season. What is still needed is a more general assessment of the multiple impacts of whole biotic communities on historic stonework, and a comparison of the relative deterioration risks of bare *vs.* plant-covered stone in a range of climatic settings.

5. Acknowledgements

I would like to acknowledge English Heritage and EPSRC (Grant no. EP/GO11338/1) for generous financial support, and Chris Wood, Alan Cathersides, Bernie Smith, Nick Cutler, Hong Zhang, Samin Ahmad, Troy Sternberg, Zoe Lee, Mark Page and other colleagues for support with the research summarised here. Alice Goudie provided invaluable bibliographic and typographical assistance.

6. References

Arino, X., Ortega-Calvo, J.J., Gomez-Bolea, A, 1995. 'Lichen colonization of the Roman pavement at Baelo Claudia (Cadiz, Spain): Biodeterioration vs. bioprotection'. *The Science of the Total Environment*, **167** (1-3): 353-363.

Caneva, G. and Roccardi, A, 1991. 'Harmful flora in the conservation of Roman monuments'. In *Biodeterioration of Cultural Property: Proceedings of the International Conference on Biodeterioration of Cultural Property, February 20-25, 1989*. Delhi: Macmillan India.

Caneva, G., Nugari, M.P. Salvadori, O, 2008. *Plant Biology for Cultural Heritage: Biodeterioration and Conservation.* Los Angeles: Getty Conservation Institute.

Carter, N.E.A. and Viles, H.A. 2005. 'Bioprotection explored: the story of a little known earth surface process'. *Geomorphology*, **67**(3-4): 273-281.

Cutler, N. and Viles, H.A. 2011. 'Eukaryotic Microorganisms and Stone Biodeterioration'. *Geomicrobiology Journal*, **27**(6-7): 630-646.

Gorbushina, A.A. and Petersen, K. 2000. 'Distribution of microorganisms on ancient wall paintings as related to associated faunal elements'. *International Biodeterioration & Biodegradation*, **46**(4): 277-284.

Jiménez-Lopez, C., Jroundi, F., Pascolini, C, 2008. 'Consolidation of quarry calcarenite by calcium carbonate precipitation induced by bacteria activated among the microbiota inhabiting the stone'. *International Biodeterioration and Biodegradation*, **62**(4): 352–63.

Lee, Z., Viles, H.A., Wood, C.H. 2009. 'Soft capping historic walls: A better way of conserving ruins?' In *English Heritage Research Project Report*, Lee, Z., Viles, H.A., Wood, C.H. (eds.) 1-69. Oxford: Oxford Rock Breakdown Laboratory.

Papida, S., Murphy, W., May, E. 2000. 'Enhancement of physical weathering of building stones by microbial populations'. *International Biodeterioration & Biodegradation*, **46**(4): 305-317.

Rodriguez-Navarro, C., Rodriguez-Gallego, M., Ben Chekroun, K., 2003. 'Conservation of ornamental stone by Myxococcus xanthus-induced carbonate biomineralization'. *Applied Environmental Microbiology*, **69**(4): 2182-2193.

Sass, O., and Viles, H.A. 2006. 'How wet are these walls? Testing a novel technique for measuring moisture in ruined walls'. *Journal of Cultural Heritage*, **7**(4): 257-263.

Seaward, M.R.D. 1997. 'Major Impacts Made by Lichens in Biodeterioration Processes'. *International Biodeterioration and Biodegradation*, **40**(24): 269-273.

Smith, B.J., McCabe, S., McAllister, D., 2010. 'A commentary on climate change, stone decay dynamics and the 'greening' of natural stone buildings: new perspectives on 'deep wetting'. *Environmental Earth Sciences*, **63**(7-8): 1691-1700.

Sternberg, T., Viles, H.A., Cathersides, A, 2010. 'Dust particulate absorption by ivy (Hedera helix L) on historic walls in urban environments'. *Science of the Total Environment*, **409**(1): 162-168.

Sternberg, T., Viles, H.A., Cathersides, A. 2011. 'Evaluating the role of ivy (Hedera helix) in moderating wall surface microclimates and contributing to the bioprotection of historic buildings'. *Building and Environment*, **46**(2): 293-297.

Viles, H.A. and Cutler, N.A. 2012. 'Global Environmental Change and the Biology of Heritage Structures'. *Global Change Biology*, **18**(8): 2406-2418.

Viles, H.A., Sternberg, T., Cathersides, A. 2011. 'Is ivy good or bad for historic walls?' *Journal of Architectural Conservation*, **17**(2): 21-41.

Warscheid, T. and Leisen, H. 2009. 'Microbiological Studies on Stone Deterioration and Development of Conservation Measures at Angkor Wat'. In *Biocolonization of stone: control, preventive methods*, Charola, A.E., McNamara, C., Koestler, R.J. (eds.) 1-18. Washington: Smithsonian Institute.

Wood, C. 2005. 'Soft capping: justifying a return to the picturesque'. *Context*, **90**(July): 22-24.