Algal and Lichen Growth Following Chemical Stone Cleaning

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Abstract

Chemical cleaning methods have commonly been used to remove soiling from sandstone building facades. There has been anecdotal evidence suggesting that algal regrowth on facades can be increased following cleaning. It is shown here that both algal and lichen growths on sandstones may be substantially increased following chemical cleaning if the cleaning agents leave residues of phosphate (a nutrient normally in limited supply) in the sandstone. The growth of algae and lichens on samples of chemically-cleaned sandstones has been followed over five years. The effects of chemical residues with respect to biological growths were found to vary substantially depending on the characteristics of the sandstone. Phosphate may be chemically bound to iron compounds in sandstones. Iron-rich sandstones can therefore retain more residual phosphate than iron-poor sandstones. The duration of increased algal growth was found to vary from two years (iron-poor sandstone) to over five years (iron-rich sandstone). Where the sandstone was of low porosity and algal growth was consequently slow to become established, increased algal growth could be delayed until three years following cleaning. Lichens appeared to be stimulated by lower amounts of phosphate, and increased lichen growth was found to be of longer duration than increased algal growth. Biological growths can be disfiguring, may encourage soiling and some are capable of causing damage to stone. These results indicate that phosphate-bearing chemical cleaning methods should be used with caution on porous stone types in situations where biological growths could cause problems.

Introduction

Chemical cleaning methods using acids and/or alkalis have commonly been used to remove soiling from building facades. In addition to removing inorganic soiling, any biological growths present at or near the stone surface at the time of cleaning are killed or removed. Most stone cleaning treatments do not, however, have any long-term biocidal effect and, in the absence of any preventative treatment, re-establishment of organisms is likely to occur on a fairly short time scale. In some cases, sandstone facades have appeared to exhibit relatively large amounts of algal growth following chemical cleaning. It is not always clear, however, whether algal regrowth is actually increased by cleaning, since the amount of growth prior to cleaning is not easy to assess on the soiled stone.

A number of different chemicals have been used for chemical cleaning of building stone. The method described here is a two-stage process using an alkaline cleaning agent followed by an acidic cleaning agent. Other chemical cleaning methods are available which use, for example, an alkaline poultice followed by a neutralizing (no cleaning action) acidic chemical or a single stage application of an acidic cleaning agent. No one chemical cleaning method will work in all circumstances and test panels are necessary to determine which method will work best in any particular situation.

The treatment dealt with here is a method that has commonly been used in Scotland for the cleaning of sandstones and granites, and involves two stages of chemical application. In the first stage an alkaline solution of sodium hydroxide (NaOH) is applied. The alkali is used to remove greasy deposits (e.g. hydrocarbons) from the stone. The alkali is washed off and a second, acidic cleaning agent is applied. This cleaning agent is a mixture of hydrofluoric (HF) and phosphoric acid (H_3PO_4). The acidic cleaning agent removes any remaining soiling from the stone which is then thoroughly washed to remove the chemicals and loosened soiling. Phosphoric acid is not used in all acidic chemical cleaning agents. The addition of phosphoric acid is intended to prevent iron migration; it is used in cleaning agents where there is the possibility of iron being washed out of the stone, leading to iron staining following cleaning.

Although the stone is thoroughly washed after cleaning, chemical residues can remain in the stone, especially in porous stone types (e.g. sandstones). Stones with very low porosity, such as granites, generally contain negligible amounts of residual chemicals after cleaning,[1] although residues may be present in pointing mortars or in weathered, more porous granites. It has been shown that up to 85 per cent of applied chemicals may be retained in some sandstones.[2,3] It is possible that residual chemicals left in sandstones following chemical cleaning could induce increased growth of some organisms if these residues could be used as nutrients. A number of elements are required by organisms as essential nutrients and some of these are normally in short supply on most building stones (e.g. phosphate and nitrate). Bird droppings can provide nutrients such as nitrate and phosphate, and some organisms (e.g. some cyanobacteria) can fix nitrogen from the air. Stone cleaning chemicals may also be a source of nutrients as their use can leave substantial chemical residues in sandstone. Where the chemicals contain phosphoric acid (e.g. some acidic cleaning agents), residual phosphate may be available to microorganisms and could stimulate increased levels of biological growth.

Methodology

To investigate whether chemical residues from stone cleaning can affect algal and lichen growth on building sandstones a test rig was constructed to hold a number of sandstone samples.[4] The test rig was located in a courtyard in Aberdeen, Scotland (OS grid ref. NJ 913 030). Three replicas of each sample (50 x 50 x 15 mm) faced north and south at an angle of 60° from horizontal. The sandstones (Cat Castle, Corsehill and Leoch: porosities 14.4%, 17.7% and 6.1%, respectively) represented a range of characteristics typical of building sandstones used in Scotland.[5] Samples were initially free of pre-existing algal growths, but were inoculated before exposure with a solution containing known algal types (*Stichococcus* sp., *Chlorococcum* sp., *Botrydiopsis* sp. and *Tetraspora* sp.) isolated from field samples taken from a range of Scottish sandstones. This ensured that all sandstones began with a similar potential to be colonized by algae. Samples consisted of untreated controls, abrasively cleaned, chemically cleaned and biocide treated sandstones. Only the results from one chemical cleaning method and the untreated control samples are dealt with in this paper. This two-stage chemical cleaning method (Table 1) has been commonly used in Scotland in the cleaning of both sandstones and granites. The methodology for its use followed that which would be used on a building facade.

The growth of algae and lichens on the samples was monitored over a period of five years (November 1992 to December 1997). Lichen growth was monitored visually by inspecting the samples at

1st treatment (alkaline)		2nd treatment (acidic)	
Active chemical	Working conc. (%)	Active chemical	Working conc. (%)
sodium hydroxide $NaOH$	25	hydrofluoric acid HF	14
		phosphoric acid H_3PO_4	28

Table 1 *Composition of chemical cleaning agents.*

approximately two-monthly intervals, noting the size and position of lichens. Algal growth was monitored at the same intervals using colour measurement to detect the presence of green algal growths. Colour measurement was performed using a chroma meter (Minolta Chroma Meter CR-210). The colour scale used was L*a*b*: L* is a measure of the brightness level (higher value = brighter), a* and b* measure the colour, a* for green (-ve) to red (+ve) and b* for blue (-ve) to yellow (+ve). Changes in green coloration can be taken as a measure of the amount of green algal growth on the surface.

The levels of water-soluble phosphate (amount available to microorganisms in a rainwater-soaked sandstone sample) in the sandstones were measured by spectrophotometry (Cecil Instruments CE373) using the molybdate blue method.

Results

Trends in algal growth (as measured by green coloration) on untreated controls and chemically-cleaned sandstones are shown in Figure 1. The most obvious trends in the data were seasonal variations. Following the establishment of algae on the samples, algal growth increased during autumn and winter when rainfall and humidity levels were higher. During spring and summer months the amount of algae decreased. There was more algal growth on north-facing (shaded) than on south-facing (intermittently sunlit) samples. In addition to these seasonal differences, the data show significant variations in algal growth attributable to chemical cleaning. The results show periods when there was significantly more algal growth on chemically-cleaned samples than on untreated control samples.

Data on lichen growth over the same five-year period are shown in Figure 2. Lichen growth was not observed on the samples until May

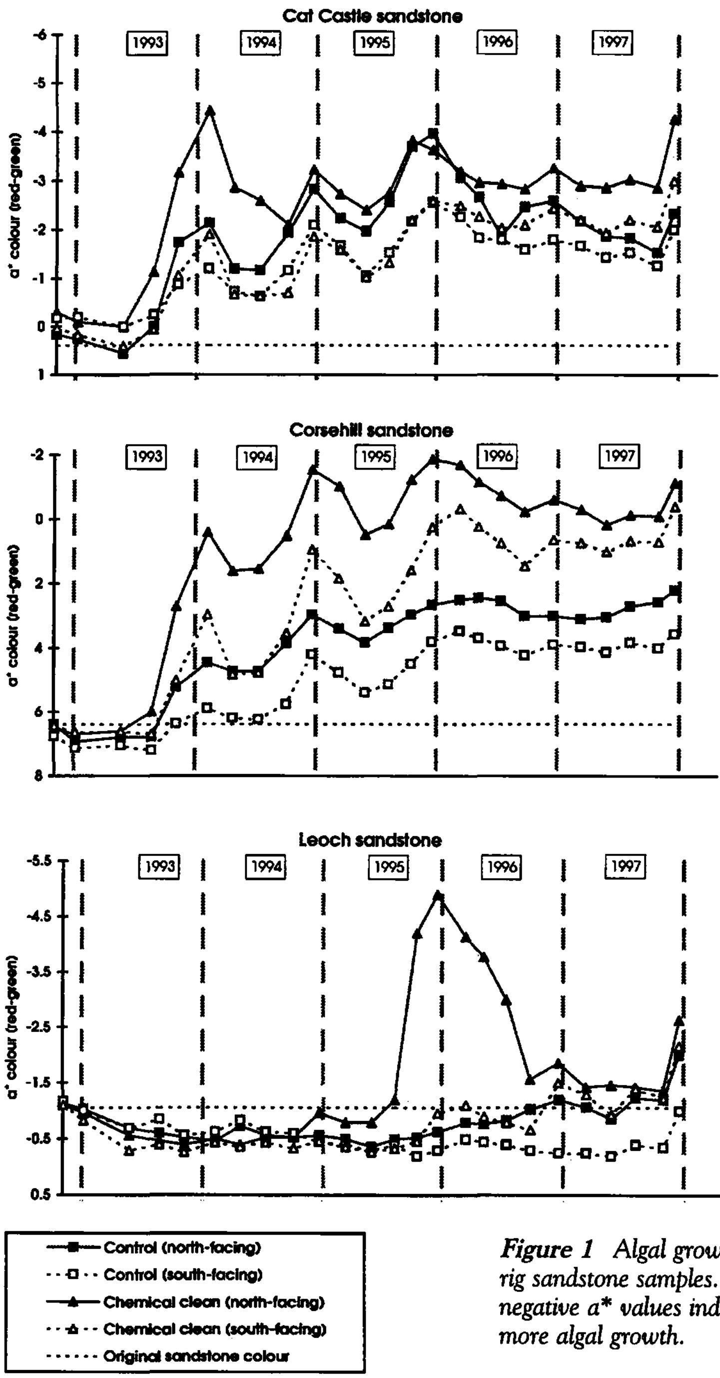

Figure 1 *Algal growth on test rig sandstone samples. More negative a* values indicate more algal growth.*

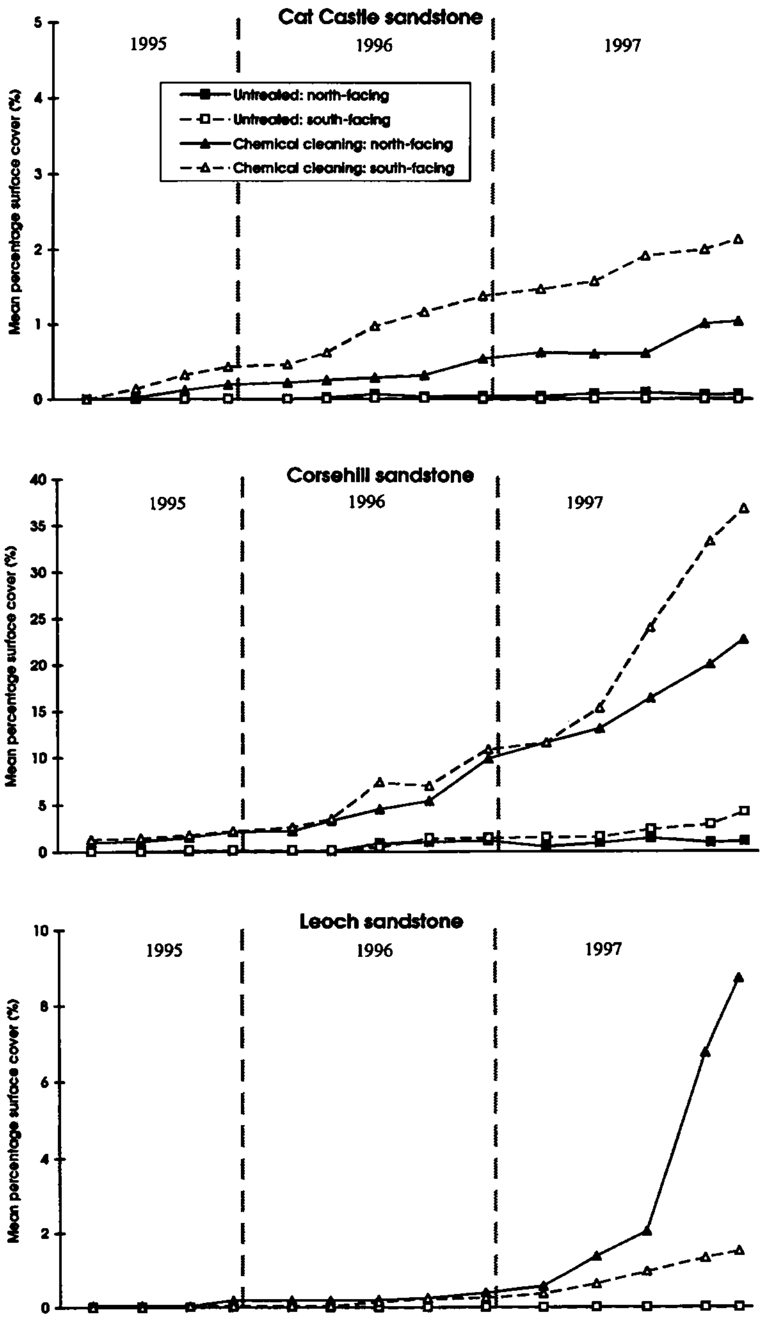

Figure 2 *Lichen growth on test rig sandstone samples. Shown as percentage surface cover.*

1995, some two and a half years after initial exposure. Seasonal effects on lichen growth were much less pronounced than those observed for algal growth. Lichens were not lost during the summer months, but there is evidence (more rapid increases in percentage coverage) that lichen growth was more rapid during the autumn and winter. On all three sandstone types there was much more lichen growth on chemically-cleaned samples than on untreated control samples. Especially large amounts of lichen growth were observed on chemically-cleaned Corsehill sandstone.

Chemical analysis (Table 2) of untreated controls and chemically-cleaned sandstones in samples that were not exposed to weathering revealed relatively high levels of water-soluble phosphate in chemically-cleaned Corsehill and Cat Castle sandstone samples (63 ppm and 64 ppm respectively). Chemically-cleaned Leoch sandstone showed lower levels of water-soluble phosphate (9 ppm), although these were still substantially elevated above the levels found in the untreated control samples (0.2–0.3 ppm).

Sandstone	Chemical cleaning	Mean conc. phosphate in sandstone (ppm)
Cat Castle	none	0.2
Cat Castle	yes	64
Corsehill	none	0.3
Corsehill	yes	63
Leoch	none	0.2
Leoch	yes	9

Table 2 *Results of analysis of levels of soluble phosphate in sandstones.*

Discussion

Differences in porosity between untreated and chemically-cleaned sandstones could have indicated that differences in biological growths were due to increased microporosity (e.g. caused by acid etching) that could increase water retention and provide more niches for colonization. No significant differences in porosity were found,[6] however, indicating that porosity changes cannot account for the observed differences in the rate of growth of algae.

It is likely that the increased algal and lichen growth observed on chemically-cleaned sandstones was due to the relatively high levels of soluble phosphate left in the sandstones by chemical cleaning. This phosphate was available as a nutrient, stimulating increased algal and lichen growth over various periods, dependent on the physical and chemical characteristics of the sandstones.

Lichens, being slow growing, generally took longer to become established on the samples than algae, and lichens were not noted on any samples until May 1995. On south-facing Leoch sandstone (which has a low porosity), however, lichen growth occurred before any algal growth. Lichens, being able to colonize drier habitats, were able to colonize this sandstone more rapidly than algae.

On Cat Castle sandstone, increased algal growth was observed on chemically-cleaned samples for two years following cleaning. Increased lichen growth on chemically-cleaned samples was, however, noted over the period of three to five years following cleaning. This may indicate that lichen growth was stimulated by lower amounts of phosphate than algal growth, or perhaps that the lichens could extract phosphate by direct contact with, or acid attack on, minerals to which the phosphate was bound.

Increased algal growth on chemically-cleaned samples lasted for at least five years on Corsehill sandstone, but for only two years on Cat Castle sandstone. On chemically-cleaned Leoch sandstone algal growth did not begin until two and a half years after cleaning. These results indicate that where chemical cleaning leaves residual phosphate in sandstones, its medium-term effects on biological growths may depend critically on the characteristics of the sandstone. In some cases the effects of chemical cleaning, with respect to biological growths, may take years to become apparent.

Algal growth was slow to become established on Leoch sandstone due to its low porosity. Since algal growth on Leoch sandstone could be stimulated by phosphate residues after three years of weathering, this indicates that the levels of residual phosphate in Leoch sandstone must still have been relatively high. It is suggested that both the delayed algal growth on Leoch sandstone and the extended period of increased algal growth on Corsehill sandstone relative to Cat Castle sandstone was due to the higher iron content of Leoch and Corsehill sandstones (Leoch 4.0%, Corsehill 1.4%, Cat Castle 0.6% Fe_2O_3). Phosphate has an affinity for iron and may therefore be retained for longer in iron-rich sandstones.

The sandstone samples used in these experiments were relatively small in size (50 x 50 x 15 mm) and were exposed at an angle of 60° to the horizontal. The sandstones were therefore highly exposed to rainfall and their behaviour is likely to most closely simulate the behaviour of exposed areas of similar sandstones on building facades. On the more sheltered areas of building facades the effects of phosphate residues on biological growths are likely to be longer lived since the rate of loss of soluble phosphate will be lower.

Conclusions

Stone cleaning methods include both abrasive methods (e.g. grit blasting), chemical methods (e.g. acid cleaning) and water washing. While water washing can be effective on limestones, soiling on sandstones and granites cannot be removed without the use of more aggressive techniques.[7] Abrasive cleaning methods can cause visible damage to the surface texture of relatively soft stone types, including many sandstones. The use of chemicals therefore appears to offer a method of cleaning that could remove soiling without any damage to the stone. While chemical cleaning of most sandstones and granites may not result in any immediate or obvious damage to the stone, it can leave a legacy of problems leading to accelerated decay rates in the future.

It has previously[8,9] been shown that chemical cleaning can leave salt residues in sandstones that may accelerate the decay of vulnerable stone types through salt crystallization within the stone. The results presented here show that residues from some chemical cleaning agents may also increase the amount of biological growth on chemically-cleaned stone. It has been shown that chemical cleaning methods, in which the acidic cleaning solution contains significant amounts of phosphoric acid, can leave residues of phosphate in sandstones. These residues are sufficient to stimulate algal and lichen growth for a period of time that is dependent on the physical and chemical characteristics of the sandstone. Algal growth may be noticed within a few months of cleaning but, depending on the stone type, increased growth may be delayed for up to three years after cleaning. Algal growth on chemically-cleaned sandstones will decline over time as the excess phosphate is lost from the stone. These results indicate, however, that for some sandstone types (e.g. those containing relatively high amounts of iron) increased algal growth may persist for more than five years following cleaning. In addition, lichen growth may be increased over a much longer period as lichens appear to be stimulated by lower levels of phosphate than are required for algal growth.

Increased algal growth is unsightly, especially on newly-cleaned stone. Although most algae appear to have little effect on sandstones, some species are capable of causing decay through size changes on wetting and drying[10] leading to spalling of the stone surface. In addition, algal growths trap dirt and can accelerate the re-soiling rate of stone.[11,12] Lichen growths are often more damaging to stone than algae. Decay may be accelerated by physical process such as size changes on wetting and drying,[13] and many lichens secrete acidic substances that are capable of causing chemical weathering of stone.[14,15] Increased algal and lichen growth in the years following chemical cleaning may therefore contribute to accelerated stone decay.

The amounts of phosphoric acid in chemical cleaning agents vary from zero up to about 30 per cent (28 per cent in this study). While the addition of phosphoric acid to cleaning agents may be necessary in some cases to avoid iron staining, it is unclear whether such high concentrations are necessary. In previous studies, phosphate levels in acidic chemical-cleaning agents of about one to two per cent have not been found to encourage algal growth.[16] Further studies would be necessary to establish the minimum concentration of phosphoric acid necessary to prevent iron staining that would, hopefully, be sufficiently low that biological growths would not also be encouraged. At present, given that high phosphate residues will cause increased biological growth, practitioners would be best advised to avoid the use of phosphate-bearing cleaning agents on stones where iron staining is unlikely to be a problem.

Biography

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Acknowledgements
Part of this work was undertaken in a research project examining algal growth

on building sandstones and the effectiveness of biocide treatments.[17,18] The research project was funded by Historic Scotland.

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