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The influence of aspect on the biological colonization of stone in Northern Ireland

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ABSTRACT

The rate and type of biological colonization of stone is influenced by a wide array of environmental factors in addition to substrate characteristics. A series of experiments was designed to compare the rate and type of biological colonization of stone at varying locations over a 21-month time period. Exposure trials were set up at nine different sites across Northern Ireland that covered a wide variety of environmental conditions. To determine aspect-related differences in colonization, blocks of Peakmoor sandstone and Portland limestone were placed on the north- and south-facing sides of purpose-designed exposure racks. Colorimetry and visual analysis were carried out on collected samples at increasing time intervals. Results showed significantly different rates of darkening and greening over time between north-facing and south-facing blocks, for both sandstone and limestone. This difference is likely to be representative of the fact that in Northern Ireland's wet climate and northern-latitude position, the north face of a building will receive less direct sunlight. Therefore north-facing blocks, once wet, will remain damp for much longer than blocks on other façades. This slow-drying phenomenon is much more hospitable for biological colonization and continued growth than the hostile environment of rapid wetting and drying cycles experienced on the south face.

1. Introduction

It is a widely accepted axiom that biological growth varies with orientation. In the northern hemisphere more luxuriant biological growth appears to occur on north-facing surfaces, whether that be the northern slope of a mountain, side of a tree trunk, or façade of a historic building. Within Northern Ireland, the authors have frequently observed large differences in the quantity (and variety) of biological colonization between north- and south-facing building façades (supported by anecdotal evidence from conservation practitioners). North-facing surfaces in the northern hemisphere will naturally receive little to no direct sunlight during the day (particularly in winter) in comparison with those that are south-facing. This will lead to differences in (a) surface temperatures and solar radiation and (b) the moisture retention of the substrate. The term 'aspect' will be used throughout this paper to refer to spatial orientation i.e., the north, east, south or west-facing façades of a building or exposure rack.

Biological colonization on stone can generally be attributed to two main groups of contributing factors: those relating to the properties of the substrate, i.e., the bioreceptivity of the stone, and environmental controls. The latter group of factors is the focus of this work, with bioreceptivity factors controlled to a certain extent by the use of one relatively homogenous stone type as the primary substrate throughout.

1.1. Environmental controls on biological colonization

Halsey et al. (1998) investigated the effects of aspect on the Lichfield Cathedral tower, in Staffordshire, England, measuring temperature, relative humidity, and the frequency of heating–cooling cycles. Results showed that the north face did not rise as much in temperature as the other faces, reaching a maximum of around 15 °C as opposed to 18–20 °C for the other three façades. The north face also demonstrated fewer heating–cooling cycles per month and fewer wetting–drying cycles. The lower frequency of environmental fluctuation may suggest less deterioration on this side from physical weathering (through, for example the crystallization or hydration/dehydration of soluble salts), but it also presents much more stable, and therefore less environmentally extreme conditions that are more suitable for colonization and continued growth.

The amount of solar radiation reaching a façade will also have an impact on the biodiversity of the substrate. Cyanobacteria have

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protective pigments and sheaths that protect them from ultraviolet radiation at levels that would be inhibitory to other microorganisms (Garcia-Pichel et al., 1993), whereas algae appear to be sensitive to solar radiation and are therefore more commonly located in shaded and moist areas (Lyalikova and Petushkova, 1991; Gaylarde and Morton, 1999). This was demonstrated on a more global than microclimatic scale by Gaylarde and Gaylarde (2005), who compared the microbiological diversity of 230 microbial biofilm samples taken from building exteriors (including stone, brick, concrete, mortar, and paint) in seven Latin American and six European countries. They found that in Latin America cyanobacteria were the dominant biomass, followed by fungi, whereas in Europe algae were the prominent biomass on all substrates, followed by cyanobacteria, with coccoid autotrophs being the most common form of organism overall. García de Miguel et al., 1995, in a study of biodeterioration on the Great Jaguar pyramid, in Guatemala, also found that cyanobacteria were the most prominent organisms and that eukaryotic algae were absent from most samples.

Caneva et al. (2008) considered the quantity and availability of moisture to be "the main determining factors for the speed at which a surface is colonized." A stone surface can be an inhospitable environment for organisms, with rapid changes in surface temperature and variation in moisture availability. This is particularly true for vertical stone surfaces, where precipitation may not directly impact the stone face and any that does will run off rapidly. This accounts for the higher levels of colonization on angled or horizontal stone surfaces on a building (such as string courses and buttress capstones) where water gathers or runs off less rapidly, allowing sufficient moisture to be retained for colonization to occur. Young and Urquhart (1998) state, "vertical façades seldom support much biological growth unless they are in regions of high humidity or are often wetted." Ortega-Calvo et al. (1993) also commented, "algae are commonly found on buildings in humid places, growing in cornices, in holes and crevices or beneath crusts where water is retained and evaporation is low." Different species of microorganism will have variable tolerances for lack of moisture; however, those species adapted for life in desert or consistently low-moisture conditions are in the minority, and a mild and humid or wet climate will inevitably encourage more biological growth than an arid region. Gillatt and Tracey (1987) have also stated that "algae are more frequent on moist than on dry sites."

As discussed, some previous research, e.g., Halsey et al. (1998), has demonstrated the difference in conditions and the potential impacts on stone weathering on differing aspects. Robinson and Williams (1996) state that "the issue of whether stone deterioration on buildings varies with aspect has rarely been discussed in any detail and remains under-researched." They also go on to comment that "where thermal changes are responsible for the deterioration one would expect to find significant differences in amounts of weathering between the north and south sides of buildings but little, if any, differences between the east and west sides."

In terms of the effects of aspect on biocolonization, and therefore potentially biodeterioration, on historic buildings, the phenomenon is well accepted, yet relatively little research has been carried out to attempt to quantify the difference in colonization (particularly the early stages) between aspects on masonry. The majority of work has been based on studies of established biological growth, and in particular on lichens (Nimis and Monte, 1988; Monte, 1991; Tretiach et al., 1991; Paradise, 1997). Mottershead et al. (2003) investigated aspect-related differences on a coastal fort in England, and found that biofilms on the north aspect were thicker and more uniform than those on the south: "…stone samples from the southern wall are less pigmented and show only a slight shade of green on their surface. The biofilm is patchy in distribution, unlike the uninterrupted layer on the surface of the north wall." Also, Krumbein et al. (2006) refer to north-facing façades being the most conducive to biofilm formation in a report by Historic Scotland.

This study will directly investigate the differences in early biocolonization between north- and south-facing stone blocks, across nine environmentally variable sites using a set of 21-month exposure trials.

2. Materials and methods

Identical exposure trial experiments were set up at nine different sites (Fig. 1) in order to represent the wide variety of local environmental conditions (see Table 1). Care was taken not to place exposure racks in areas that were sheltered or had overhanging vegetation. All exposure racks were aligned north–south using a compass.

The exposure trials consisted of a series of investigations, consisting of specifically designed holding racks where stones were set at a 45° angle with the aim of representing slow run-off areas on historic buildings (such as buttress capstones).

The primary experiment was designed to investigate the overall rate, type, and amount of colonization on the exposed stone surfaces over time. Designated blocks at each site were collected from both aspects at intervals of 9, 13, 17, and 21 months, with additional blocks collected at 6, 11, 15, and 19 months from the north-facing sample sets only. This was due to the fact that more rapid colonization and growth was expected on north-facing blocks. All remaining blocks on both aspects were photographed using a Fujifilm A920 camera at each site visit.

Due to the accelerated initial rate of greening observed at the Omagh site, extra blocks were put out on both aspects, halfway through the exposure period (September 2010) to investigate the rate of soiling within the first few months of exposure. These then represented a set of 2- and 4-month values for the Omagh site only (Fig. 4F).

Once collected, all stones were stored at approximately 4 °C in a standard refrigerator that was used solely for these samples. The refrigerator was used (a) to prevent contamination of samples by airborne particles and (b) to slow biological degradation. All collected blocks were allowed to dry for 2–4 wk before colorimetric readings were taken.

2.1. Materials

The main type of sandstone used for the exposure trial blocks was Peakmoor sandstone, a Carboniferous, non-calcareous, quartz sandstone that is still actively quarried near Matlock, England. Peakmoor sandstone is used throughout the UK and has been used in Northern Ireland in recent years for stone replacement, due to its similarity in appearance to historically used local stone types.

To compare potential aspect-related soiling differences between different stone types, two mid- and end-time (i.e., 13 and 21-month) Portland limestone blocks were placed on both the north- and south-facing samples at each site. Portland limestone is an oolitic, Jurassic limestone from England that has historically been used widely throughout the United Kingdom for many prestigious buildings and monuments, e.g., St. Paul's Cathedral in London, and Belfast City Hall. See Table 2 for substrate characteristics for both stone types.

2.2. Colorimetry

Prieto et al. (2004) investigated the efficacy of three different methods for estimating biofilm mass on stone samples in the