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Short communication

Can plants keep ruins dry? A quantitative assessment of the effect of soft capping on rainwater flows over ruined walls

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ABSTRACT

The world's stone heritage is constantly decaying. Rainwater is among the most important causes of stone weathering, both directly by facilitating chemical and physical weathering, and indirectly through promoting algal growth. It has deteriorative effects on historic wall surfaces, especially on the faces of ruined walls without a protective roof. To counter this decay two conservation strategies have been deployed: hard capping, which involves consolidating the wall head using mortar and stone, and soft capping, which involves installing a cap of soil covered by vegetation on the wall head. Amongst many benefits of soft capping, it should absorb more rainwater (in a similar way to the well-studied role of green roofs) and shed water away from the wall face. By simulating rain on hard and soft-capped experimental test walls in a temperate climate, and measuring moisture and runoff dynamics, we found that soft caps lowered the amount of rainwater running down the underlying wall face by more than seven times compared to hard caps, a reduction of 87%. Higher absorption and evaporation rates accounted for 89% of this reduction in surface runoff of soft capped walls, whilst 11% was attributable to water shedding. Soft caps facing North-East shed more water than South-West facing caps, probably because of the greater width of overhanging growth on the North-East facing side. Our findings show that soft capping can be an effective strategy to counter stone decay and algal soiling caused by runoff on historic wall faces.

1. Introduction

Much of the world's built heritage is made of stone, and stone is prone to decay. Alongside stone characteristics, environmental influences are major determinants of decay rates (Smith et al., 2008). Conservation strategies therefore aim to slow down decay rates of stone heritage by limiting the negative influences that the environment can exert. The main approach is to install protective measures that shield stone structures from damaging environmental conditions. Many different environmental factors, singly and in combination, can act as weathering agents (Camuffo, 1998), including temperature (Smith et al., 2008), wind (Camuffo, 1995), salt (Goudie and Viles, 1997; Charola, 2000), pollution and acid deposition (Charola and Ware, 2002), microbiological growths (Gaylarde et al., 2003; Warscheid and Braams, 2000) and water (Camuffo, 1995).

Water in the form of rainfall is one of the most important direct and indirect causes of stone weathering (Camuffo, 1995; Steiger et al., 2011). It has deteriorative effects on historic wall surfaces, especially on the face of ruined walls where the protective role of roofs has been lost. Apart from directly increasing weathering rates (for an overview of the mechanisms through which water causes weathering see Camuffo, 1995), rainwater also promotes the growth of (micro)algae (Bellinzoni et al., 2003; Gorbushina, 2007; Häubner et al., 2006), as well as fungi, cyanobacteria and heterotrophic bacteria (Gorbushina, 2007). This biological growth leads to biodegradation, which on stone surfaces consists of bioweathering and biofouling (Cutler and Viles, 2010). Bioweathering is the physical breakdown and chemical deterioration of stone that is directly attributable to biological activity (Cutler and Viles, 2010; Gaylarde et al., 2003; Warscheid and Braams, 2000). Bioweathering ranges from physical effects like increased water retention and the changing of thermo-hygric properties to chemical processes like acidolytic and oxido-reductive biocorrosion (Warscheid and Braams, 2000). Biofouling comprises all negative aesthetic impacts that arise through superficial biological growth (Cutler and Viles, 2010), most importantly the staining of wall surfaces. Both algal and fungal pigments (Cutler and Viles,

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2010; Cutler et al., 2013; Gaylarde et al., 2003), and particulates trapped in biofilms (Saiz-Jimenez, 1997; Viles et al., 2002a; Viles and Gorbushina, 2003) can cause staining.

To decrease the negative effects of rainwater (and temperature fluctuations) on stone heritage, particularly on ruined walls, two main types of conservation strategies exist: hard capping and soft capping (Lee et al., 2009; Viles and Wood, 2007). Hard capping has been widely implemented in the UK since the 1920s (Lee et al., 2009; Morton et al., 2011). It involves consolidating the wall head using mortar and stone. The aim of the hard cap is to minimise water ingress into the wall head and allow rainwater to run off the wall quickly. Although this works in the short term and the original look of the wall can be maintained, hard capping also has disadvantages (Viles and Wood, 2007). Hard caps protect the wall head and core, but wall surfaces are left unprotected against rainwater. Secondly, hard caps made with impermeable, hard cements crack open, due to differences in thermal expansion between cement and the original materials. This then allows water in, which results in freeze-thaw damage on the wall head (Lee et al., 2009). Cements on the other hand also prevent moisture from escaping the wall, resulting in more damage (Lee et al., 2009). Furthermore, hard capping is expensive to install and requires extensive long term maintenance. Because of these disadvantages, soft capping has been suggested as an alternative conservation strategy for ruins (Viles and Wood, 2007).

Soft capping involves installing a cap of soil covered by vegetation, often turf or sedums, on top of a ruined wall (Viles and Wood, 2007). Soft capping appears to have been first used as a conservation strategy in the early twentieth century, on a limited scale in Scotland. Interest revived in the early 1980s when regional English Heritage teams started experimenting with soft capping approaches (Wood, 2005). By the mid-1990s applying the soft capping technique became more widespread (Morton et al., 2011; see for example Tolley et al., 2000), and in 2001 the first scientific experiments on soft capping started (Wood, 2005; Viles et al., 2002b). Currently, the soft capping technique is applied at over 50 sites in Northwestern Europe, predominantly in the UK and Sweden (Morton et al., 2011). Objectively, soft caps have some important advantages over hard caps. First of all soft caps are relatively cheap and easy to install, they form a reversible intervention, and can have lower maintenance costs (Viles and Wood, 2007). Furthermore both lab and field experiments have demonstrated that soft caps act as a thermal insulator, reducing temperature fluctuations and the number of freeze-thaw cycles (Lee et al., 2009; Viles and Wood, 2007). In lab experiments soft caps were also shown to absorb rainwater and limit water ingress into the core of the walls (Viles et al., 2002b). Some evidence was found that this occurs in the field as well (Lee et al., 2009; Viles and Wood, 2007). More conclusive results on water ingress were found in a field experiment that showed that the cores of soft capped walls are drier than those of hard capped walls (Sass and Viles, 2006). These findings suggest that soft caps reduce the amount of water filtering down into the wall core, despite the fact that they absorb rainwater—presumably because the water is used effectively by the plants. An additional advantage of soft caps is that they increase local biodiversity (Francis, 2011; Viles and Wood, 2007). However, soft capping changes the appearance of a heritage site more drastically than hard capping. Overall, studies so far indicate that soft capping is an effective conservation strategy with many advantages over hard capping.

Soft caps are structurally very similar to green roofs, which are essentially roofs covered by a layer of soil with vegetation growing on it. Among other advantages such as thermal insulation and increased green space and biodiversity in cities, green roofs are often predominantly aimed at reducing rainwater runoff, which is an important problem in dense urban areas where most surfaces are impervious. Green roofs have been studied extensively and their water retaining capabilities and effect on runoff are well known. More than half the water that falls on these roofs is (temporarily) stored there, with measured retention percentages ranging from 46% to 87% (Berndtsson, 2010; Gregoire and Clausen, 2011; VanWoert et al., 2005). Water runoff from green roofs is reduced compared to hard roofs because of the water's retention within the green roof materials and its eventual return to the atmosphere via evapotranspiration (Bengtsson et al., 2005). Based on multiple previous studies, Mentens et al. (2006) found an average runoff reduction of 54%.

Given their similarity, soft caps may well reduce rainwater runoff as effectively as green roofs. Such runoff water is an important influence on deterioration and microbiological soiling on the faces of ruined walls. In qualitative terms, it is clear that hard caps are likely to result in wetter wall surfaces, because they force rainwater to quickly run off the cap and down the wall surface. Soft caps on the other hand are likely to keep wall surfaces drier; several authors observed that soft caps retain water (Lee et al., 2009; Viles et al., 2002b; Viles and Wood, 2007), and noticed that soft caps can shed water off the wall (Lee et al., 2009; Viles and Wood, 2007). However, there is as yet no quantitative data with which to compare the performance of soft capping vs hard capping in terms of runoff down the wall face.

To assess whether soft caps are an effective way of reducing runoff down walls, it is necessary to directly compare the hydrological behaviour of soft and hard-capped walls. In order to do this, the different water flows from the caps must be defined. When rain falls on a cap, the water can end up following four different pathways (Fig. 1a). Firstly, it can evaporate back into the air. Secondly, the rainwater can be absorbed by the materials forming the cap, after which it may evaporate, or make its way to the wall core. For soft caps, the absorbed water may be used or transpired by plants. Thirdly, it can run down the wall surface. And fourthly, it can be shed off the wall, and never touch the wall surface. Out of these four pathways, only surface runoff (temporarily) wets the wall surface, resulting in increased weathering and biofouling of the surface.

This study aims to provide quantitative evidence of the effectiveness of soft caps vs hard caps in reducing runoff down the faces of ruined walls through partitioning rainfall into the four pathways. Rainfall simulation experiments were carried out on three test walls to investigate three research questions, i.e. (a) How much runoff water flows down wall faces under soft vs hard-capped tops? (b) How much does shedding water away from the wall faces contribute to reducing water runoff on soft and hard-capped walls? and (c) How and why does the amount of water shed away from wall faces vary between different areas of soft capping?

2. Materials and methods

2.1. Test walls

Experiments were performed on three test walls built in 2007 of Cotswold Limestone to a traditional design (with two dressed stone faces and a rubble core) to mimic historic ruined (Fig. 1). Two of the test walls are soft capped, and the third one is hard capped, as part of a wider project to compare the effectiveness of soft vs hard capping techniques. The walls were soft capped using a simple design with turf acquired from a nearby meadow overlying a screened loam soil of c. 5–10 cm thickness with added slate chippings. Sedum plants were later added to the edges of the soft capping to improve the stability of the edges. The hard capping was