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Bioreceptivity index for granitic rocks used as construction material

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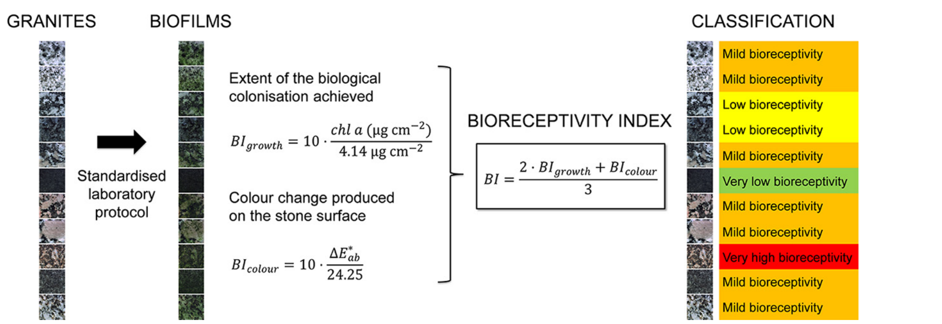
HIGHLIGHTS

- A simple, robust and well-founded bioreceptivity index (*BI*) is proposed.
- Granites are qualitatively classified according to their bioreceptivity.
- The *BI* can be used as a decision-making tool for selecting appropriate stones.
- A standardised protocol enables calculation of *BI* for new lithotypes.

GRAPHICAL ABSTRACT



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ABSTRACT

Bioreceptivity is a fundamental concept in the ornamental stone industry and in the fields of cultural heritage and civil engineering to understand the susceptibility of stone constructions to biological colonisation and subsequent biodeterioration. However, a bioreceptivity index (*BI*) has not yet been established for any construction material. The aim of the present study is developing a simple, robust and well-founded *BI* for granitic rocks. For this purpose, a standardised laboratory protocol was used to grow phototrophic biofilms on several varieties of granite. The colonisation was then assessed by chlorophyll fluorescence and colour measurements. Based on the results thus obtained, a *BI* including two components (BI_{growth} and BI_{colour}) is proposed. BI_{growth} quantifies the extent of the biological growth and BI_{colour} quantifies the colour change undergone by the stone due to the colonisation, which can be considered the bioreceptivity perceptible to the human eye. The values of *BI*, BI_{growth} and BI_{colour} were fitted to a scale of 0–10, thus enabling qualitative classification of the lithotypes according to their primary bioreceptivity. Eleven varieties of granite commonly used as construction material and with a honed surface finish (one variety with three additional surface finishes: polished, sawn and sanded) were thus assigned the corresponding *BI*, which represents a new quality factor for the stone industry. The index can therefore be used by end-users as a decision-making tool in the selection of appropriate lithotypes for building and/or ornamental purposes.

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1. Introduction

Subaerial biofilms are microbial communities embedded in a matrix of extracellular polymeric substances (EPS) that develop on solid mineral surfaces exposed to the atmosphere (Gorbushina, 2007). The colonisation of stone-made buildings and monuments by subaerial biofilms can result in high conservation and reparation costs and also in irretrievable loss of heritage due to biodeterioration processes that cause aesthetic, chemical and physical decay (Crispim and Gaylarde, 2005; Prieto and Sanmartín, 2016; Warscheid and Braams, 2000). As all exposed stone surfaces are susceptible to being colonised, minimizing the colonisation can be considered a key strategy for preventing

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biodeterioration. In addition, microbial colonisation of buildings may be considered aesthetically desirable, while also providing protection against some types of weathering (Bartoli et al., 2014; Viles and Cutler, 2012) and being beneficial to the environment (Manso et al., 2015; Pérez et al., 2014). In this regard, researchers have even designed cementitious materials with physico-chemical properties specifically aimed at enhancing the bioreceptivity (Manso et al., 2014a, 2014b). The choice of the lithotype used for construction and/or replacement in stone-made heritage should therefore take into account its susceptibility to being colonised, i.e. its bioreceptivity.

The term "bioreceptivity", introduced by Guillitte (1995) as an alternative to the term "susceptibility" for use in building ecology studies, is defined as the aptitude of a material to be colonised by living organisms. This concept focuses on the characteristics of the material that allow colonisation to take place rather than on the effects that the organisms have on the colonised materials (biodeterioration). Guillitte (1995) also established differences between "primary bioreceptivity" (the initial bioreceptivity of a material which has not yet been exposed to colonisation), "secondary bioreceptivity" (the potential of colonisation when the properties of a material have undergone a change due to the action of the colonising organisms or other factors) and "tertiary bioreceptivity" (the bioreceptivity of a material after undergoing treatments such as consolidation, coating, etc.). The bioreceptivity can be investigated by applying specific microorganisms or groups of microorganisms to the material in question and incubating the samples under optimal conditions for growth of the microorganisms (Guillite and Dreesen, 1995). On the basis of these principles, the study of the bioreceptivity of building stone aimed at preventing (or, in some cases, enhancing) biofilm formation should focus on the primary bioreceptivity of the material to pioneering colonisers, as the accumulation of photosynthetic biomass on the stone surface provides a supply of organic nutrients for the heterotrophic microflora that cause biodeterioration (Chertov et al., 2004; Warscheid and Braams, 2000).

Guillitte (1995) recommended carrying out integrated multidisciplinary studies under standardised (as far as possible) experimental conditions, using bioreceptivity tests similar to those used to determine the physico-chemical properties of materials. Some researchers have attempted to develop standardised laboratory tests based on the procedure proposed by Guillite and Dreesen (1995) for assessing the bioreceptivity of stone materials. Shirakawa et al. (2003) proposed an experimental set-up involving characterisation of stone samples, isolation and growth of fungi, inoculation, incubation and quantification of biomass. Guillite and Dreesen (1995), Miller et al. (2008) and Prieto and Silva (2005) have also developed techniques for inoculating stone samples and incubating phototrophic biofilms in growth chambers. Such laboratory experiments are crucial for addressing temporal and spatial variability and enhancing statistical data. Hence, the standardisation of laboratory protocols and the use of appropriate inocula to induce the formation of environmental-like biofilms may enable the development of a bioreceptivity index, as suggested by Guillitte (1995). More recently, Miller et al. (2012) also indicated the need to standardise laboratory protocols, which would enable generation of a database concerning the primary bioreceptivity of lithotypes used in building construction, as well as the definition of a bioreceptivity index. Such an index would provide users with information about the colonisation risk and help them choose a material depending on whether or not colonisation is desirable. It could also provide information about the effectiveness of different treatments or could be used to provide weighted biotic indices determined using different materials.

A bioreceptivity index has not yet been established for any stone material, as this requires a complex study analysing a wide variety of rocks used in construction, as well as an appropriate inoculum and a standardised laboratory protocol for biofilm development. In previous studies, stable multi-species phototrophic cultures were derived from natural subaerial biofilms and taxonomically characterised, revealing them to be complex microbial communities composed by common pioneer species that colonise building stone surfaces, including granite (Vázquez-Nion et al., 2016). A standardised laboratory protocol in which multi-species phototrophic cultures were used to induce environmental-like colonisation of granitic stone was also developed, and the potential use of these cultures as inocula in experiments aimed at studying the bioreceptivity of granitic rocks was evaluated (Vázquez-Nion et al., 2017). One of these cultures, comprising several taxa including Bryophyta, Charophyta, Chlorophyta and Cyanobacteria, was particularly suitable for this purpose due to its microbial richness, rapid adaptability to the substratum and high capacity for colonisation. Finally, the inoculum and experimental protocol described herein were used to assess the influence of the physical and chemical properties of several types of granite, commonly used as building material and/or ornamental stone, on their primary bioreceptivity to phototrophic biofilms (Vázquez-Nion et al., 2018). The aim of the present work is developing a bioreceptivity index (*BI*) for granitic rocks based on the previously reported data (Vázquez-Nion et al., 2018). This index would enable classification of different types of granite on a scale according to their susceptibility to biological colonisation, which could be considered a new quality factor for the building stone industry. Eleven varieties of granite, commonly used as construction material, were each assigned the corresponding *BI*. The index could therefore be transferred to end-users (e.g. architects, engineers, conservators/restorers) as a decision-making tool for selecting appropriate lithotypes for use in new constructions and to replace materials in existing structures.

2. Materials and methods

2.1. Characterisation of lithotypes studied

Eleven varieties of stone, commonly used as construction material in Spain, were selected for the development of the bioreceptivity index (Table 1). Nine of the eleven lithotypes studied are petrographically classified as granitic rocks, according to Le Maitre (2002), while the other two (LCL and NSA) were found to be other types of plutonic rocks. These rocks were included in the study because they are commercially available under the denomination "granite", possibly due to their similar grain patterns. For practical purposes, the eleven lithotypes studied will hereafter be referred to as "granites". Freshly cut quarry samples of the eleven varieties of stone studied were used in all experimental procedures. The same surface finish was achieved in all stone samples (honed) in order to enable comparisons between the types of rock independently of the different surface finishes that can be applied to them. In samples of one of the lithotypes (granite SIN), additional surface finishes (polished, honed, sawn and sanded) were achieved in order to assess the influence of the roughness on the bioreceptivity, independently of the inherent properties of the stone.

The lithotypes studied were mineralogically, chemically and physically characterised. The properties of the rocks analysed and the methods used to determine these are indicated in Table 2. The results obtained for each of the rocks and surface finishes studied have previously been described in detail (Vázquez-Nion et al., 2018).

2.2. Procedure for subaerial biofilm formation

A phototrophic multi-species culture, derived from a natural biofilm grown on the outer granite walls of the Monastery of San Martín Pinario (Santiago de Compostela, NW Spain) and composed by several taxa, including Bryophyta (*Syntrichia ruralis* protonemata), Charophyta (*Klebsormidium* sp.), Chlorophyta (*Bracteacoccus* sp., *Chlamydomonas* sp., *Chlorella* sp. and *Stichococcus bacillaris*) and Cyanobacteria (*Aphanocapsa* sp. and *Leptolyngbya cebennensis*), was used as the inoculum for the formation of biofilms in laboratory. This culture has previously been described in detail (as culture C5) by Vázquez-Nion et al. (2016, 2017).

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