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Choosing between sides in the battle for pioneer colonization of schist in the Côa Valley Archaeological Park: a community ecology perspective

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ABSTRACT

Lichens and bryophytes are the dominant colonizers of rock-art on schist in the Côa Valley Archaeological Park (Vila Nova de Foz Côa, north-east Portugal). They should play an important role in the process of biologically induced deterioration of the engraved surfaces, yet little is known about the composition and distribution of these communities and how they respond to local environmental constraints. This study provides a first detailed survey of lichen and bryophyte species assemblages on vertical schist surfaces in the Côa Valley, and assesses the effect of slope aspect on the composition of those assemblages, with the aim of providing a selection of the most appropriate species for future approaches of biologically induced rock-art deterioration. Ninety lichens and forty one bryophytes were identified on a set of twenty four rock surfaces, with significant variation in the composition of their assemblages dependent on slope aspect, here analysed in detail. The potential implications of such variation for differential rock-art deterioration are also discussed. Based on their frequency and abundance at opposite slopes in the Côa Valley, three crustose lichens (*Aspicilia hoffmanniana*, *Caloplaca subsoluta* and *Lecanora pseudistera*) were selected to address the phenomenon of lichen-induced weathering under the effect of major environmental constraints. An emphasis is given on the need to directly quantify the impacts of individual species and species assemblages before assuming the effective role of biological activity in (differential) rock surface weathering.

1. Introduction

The Côa Valley Archaeological Park (Vila Nova de Foz Côa, north-east Portugal) is a UNESCO World Heritage site holding the most remarkable collection of open-air Prehistoric rock-art in the Iberian Peninsula (Baptista, 2009) and the longest rock-art cycle known in western Europe (Baptista and Fernandes, 2007), ranging from the Upper Palaeolithic (Zilhão, 1995) to the early modern era, with important representations from the Neolithic and the Iron Age as well as Historical and Contemporary (Baptista, 2009). These are preserved on approximately 1000 vertical schist surfaces located along the steep slopes of the Côa Valley, and extending into a portion of the Douro riverbanks (Aubry et al., 2012; Fernandes, 2012).

Archaeologists have sought to understand the currently observed pattern of clustering and orientation of the engraved surfaces in the Côa Valley, mainly exposed toward the south-south-east (Baptista and García Díez, 2002) and spawned a whole series of papers on its likely origin, with contradictory opinions regarding the influence of either human choice or natural phenomena (*e.g.* Aubry et al., 2012; Baptista and García Diez, 2002; Fernandes, 2010). The consensus viewpoint is that a suite of highly complex and interacting physical, chemical and biological processes operate on these surfaces, whose knowledge is crucial for open-air rock-art conservation (Fernandes, 2004). Lichens and bryophytes (mosses and liverworts) are known to have a wide range of direct and indirect impacts on rock surfaces (Adamo and Violante, 2000; Altieri and Ricci, 1997; Chen et al., 2000; de los Rios et al., 2004; Shirzadian and Uniyal, 2008; Warscheid and Braams, 2000), and are likely to be the main agents of biologically induced weathering in the Côa River Valley, given their prevalence over other colonizing organisms. Based on the well-known effects of aspect in the occurrence

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and distribution of lichens and bryophytes on rock surfaces (*e.g.* John and Dale, 1991; Hespanhol et al., 2010, 2011; Pentecost, 1979) and considering the recent demonstrations of the influence of aspect in the weathering ability of individual species (Adamson et al., 2013; Hall et al., 2005), one might be led to overestimate the role of bryophyte- and lichen-induced processes in differential weathering, unless changes brought about by a number of factors are also accounted for, including: 1) the local- and micro-scale patterns of community structure, composition and distribution (Kuntz and Larson, 2006); 2) the internal readjustments of species assemblages as a result of ecological succession (Woolhouse et al., 1985); 3) the impact of several other physical and chemical agents (Hall et al., 2012), superimposed upon the effect of lichen and bryophyte growth on rock surfaces – and certainly interacting with it – that are simultaneously affected by aspect, namely water and temperature regimes (Caneva et al., 2008; Viles, 1995). The nature and extent of the impact of lichen and bryophyte assemblages upon rock surfaces in the Côa Valley, although still poorly understood, is thus expected to depend on the weathering ability of individual species (Favero-Longo et al., 2005; Prieto et al., 1997) and surrounding environment, as well as on the intrinsic properties of the substrate (Guillite, 1995; Prieto and Silva, 2005).

The ecological determinants of lichen and bryophyte distribution on monuments have been studied by Prieto et al. (1995, 1999) and Sparrius et al. (2007) on granite and limestone churches in Spain and The Netherlands, respectively; by Steinbauer et al. (2013) and Weber and Büdel (2001) on medieval castles in Germany; and by Nascimbene et al. (2009) and Nascimbene and Salvadori (2008), on calcareous statues in Italy. Prevailing microclimatic conditions of light, water and temperature regimes, rock pH and nutrient availability are as much influential in cultural environments (Adamson et al., 2013; Carter and Viles, 2004; Hall et al., 2012; Prieto et al., 1995, 1999; Steinbauer et al., 2013) as they are on natural contexts (Prieto et al., 1994).

The use of community ecology to address interactions within and between species assemblages on monuments has been pioneered by the works of Monte (1991) and Ramette (2007), but followed by few researchers (Barberousse et al., 2006; Sparrius et al., 2007; Steinbauer et al., 2013; Ortega-Morales et al., 2013), probably because such an approach is usually dependent on field recognition of all colonizing organisms up to the species level, which for many groups such as bacteria, fungi or algae is highly demanding, and results in large, complex data sets. Data interpretation in community ecology has long been relying on multivariate techniques such as ordination (Legendre and Legendre, 1998) that allows extracting the underlying structure out of such complexity and relating this structure to environmental variables, displayed in the reduced space of a diagram (ter Braak and Verdonschot, 1995). It is therefore considered an excellent tool to evaluate differences in species composition between samples and to identify the environmental variables responsible for those differences, in a single analysis (van den Brink et al., 2003).

Despite the already mentioned existing studies about the influence of macro and micro-scale factors on the structure of lichen and bryophyte communities, relatively little research has been carried out to untangle the contributions of aspect to observed changes in the composition and development of lichen and bryophyte assemblages on vertical schist surfaces. Studies concerning the lichen and bryophyte flora in the Côa Valley Archaeological Park have focused mostly on biodiversity assessments (Caldas et al., 2002; Romão, 1999; Vänskä, 2001), aiming at identifying some of the most frequent species on the engraved surfaces, but do not consider the processes that structure their occurrence and distribution at the local-scale. The purpose of this study is to specifically address the occurrence patterns of lichen and bryophyte species assemblages on vertical schist surfaces under the influence of opposite slope aspect in order to (1) assess the effect of slope aspect on lichen and bryophyte species richness and composition in the Côa Valley Archaeological Park and (2) provide a selection of species representing the local-scale changes in these communities that can be related to aspect, and to their respective role in the deterioration of the Côa Valley's open-air rock-art.

An important outcome of the community ecology approach is that knowledge about species–environment relationships allows for species colonizing rock surfaces to be used as early indicators of the effects of environmental change, by relating species assemblages to environmental drivers that are relevant for rock-art conservation (Prieto et al., 1999). Such knowledge is also critical for the choice of the most appropriate preventive or cleaning methods (Nascimbene et al., 2009), if that is to be considered in the framework of the Côa Valley's rock-art conservation plan.

2. Material and methods

2.1. The study area

The study area is situated in the valley of River Côa close to its confluence with River Douro, approximately 200 km upstream of the mouth of the Douro, in the city of Oporto.

The lithology of the Côa River Valley is dominated by metasedimentary rocks of the schist–greywacke complex said by Ribeiro (2001) to be ranging in age from the Precambrian to the Ordovician. The Côa and its tributary streams have cut deeply through the schist and metagreywacke basement, taking advantage of pre-existing major faults roughly oriented from NE to SW (Aubry et al., 2012) and forming numerous steep-walled valleys that play a major influence on regional landscape. A special feature resulting from the down-cutting of the Côa Valley is the occurrence of massive vertical schist surfaces arranged in layers along the valley's slopes (Fig. 1), which have been gradually exposed by rock toppling, *i.e.* a sequence of gravity-induced block displacement after splitting of vertically orientated joints, along the schistosity plane (Fernandes, 2006; Fernandes and Rodrigues, 2008). The exposed surfaces bear numerous cracks and crevices of different sizes, some widespread splintering and alveolization, besides carbonate efflorescences and intense oxidation (Fernandes, 2012). According to Rebelo and Cordeiro (1997) heavily weathered surfaces must have undergone multiple freeze–thaw cycles during the cold period of the late glacial maximum (approximately 13,000 to 10,000 yBP) whereas smoother and reasonably well preserved surfaces, have most probably been covered by a protective, impermeabilizing clay coating from periglacial colluvial deposits, and lately uncovered thanks to the progressive erosion of those deposits.

Climate in the study area is predominantly dry meso-Mediterranean (Costa et al., 1998), sheltered from the Atlantic influence by mountains to the north and the west, but thermo-Mediterranean microclimates are usually produced in the bottom of the valleys, where temperature is frequently above 40 °C in late spring and summer (June–August), daily thermal amplitudes may reach 10°–15 °C and mean annual precipitation is often bellow 400 mm (Fernandes, 2012).

2.2. Sampling design

The study was conducted at three sites: Vale de José Esteves, Vale do Forno and Foz do Côa, following Aubry et al. (2012) in their assessment of differential weathering in the Côa Valley. At each site, data was collected from four randomly selected vertical schist surfaces, independently of the occurrence of rock-art, within each of the two opposing slopes (facing NW and SE, respectively),