International Biodeterioration & Biodegradation 134 (2018) 31–38

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Wind-driven rain as a bioclimatic factor affecting the biological colonization at the archaeological site of Pompeii, Italy

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ARTICLE INFO

Keywords:
Ecology of biodeterioration
Monument conservation
Incident rainfall
Dominant winds
Stone deterioration
Microbial colonization

ABSTRACT

The weathering role of Wind-Driven Rain (WDR) on buildings is widely recognised from a physical point of view, but the influence of WDR on Biological Growth (BG) on stone materials to cause biodeterioration is still not well studied. Following our previous results from the Roman area, the UNESCO site of Pompeii for its importance was selected to further test relationships between WDR and BG. We collated and analysed climatic data (rainfall, direction and intensity of winds) between 2010 and 2015 to delineate the thermo-pluvial diagram and extrapolate Dominant Winds (DW) and WDR. Data on BG, consisting mainly of cyanobacteria, algae and lichens, were also collected through sampling, direct observations and analysis of high-quality photos. The climatic elaborations highlighted a dominance of the West wind influencing WDR. The BG was more prominent on the northern and western exposures, while it was considerably less extensive on the southern walls. Our results also showed that water from WDR, together with the lower temperature in the northern exposure and poor ventilation, can all affect wetness and had a profound role in the promotion of BG. Our analyses suggest that the protection of building walls should be different according to the exposure conditions in the formulation of preventive strategies for conservation.

1. Introduction

The study of climate change and its impacts on both biotic and abiotic components of any ecosystems is becoming increasingly important (Houghton et al., 1990; Parmesan and Yohe, 2003; Meehl et al., 2007; IPCC, 2014). Regarding the preservation of cultural heritage, extreme rainfalls, increased temperatures, increased intensity of winds and tsunamis have all been linked to an accelerated deterioration of monuments (Garcia-Vallès et al., 1998; Lefèvre and Sabbioni, 2009; Erkal et al., 2012; Gu et al., 2013; Brimblecombe, 2014). High temperatures, freezing events, water evaporation, as well as the crystallization of salts and deposition of anthropogenic pollutants can contribute to monument weathering through processes of erosion and disaggregation (Grossi et al., 2007; Zedef et al., 2007; Mitchell and Gu, 2000; Kanani and Zandi, 2011). In addition, biological colonization and the resulting biodeterioration also depend on a variety of environmental conditions, which include microclimatic conditions influencing relative humidity (RH), local temperatures and lighting, as well as the bioreceptivity of stone surface (Ortega-Calvo et al., 1991; Guillitte, 1995; Caneva et al., 2008; Miller et al., 2012; Sterflinger et al., 2018). Water and light availability can also affect and change the typical biodeterioration patterns on archaeological sites (Caneva et al., 2005, 2015; 2016; Liu et al., 2018). Biogeochemical cycling of essential nutrients (e.g., carbon, nitrogen and sulphur) is accelerated and involved with the deterioration of stone materials in cultural heritage sites in Southeast Asia (Li et al., 2010; Kusumi et al., 2013; Meng et al., 2016, 2017; Xu et al., 2018).

Bioclimate describes the environmental factors (annual trends of rainfall and temperatures and their combined effects) in relation to their impacts on biological communities (Odum et al., 1971). The climatic conditions of an area have high relevance to the biological community and its growth, and the weathering processes of physic-chemical origin (Caneva et al., 2008). At the local scale, the effects of rainfall on buildings in natural and urban contexts have been widely studied among the various climatic factors (Blocken and Carmeliet, 2004; Blocken et al., 2011). Several studies investigated the importance of Wind-Driven Rain (WDR), i.e., the annual rainfall (mm) coming from each cardinal wind direction in altering the hydrothermal performance and durability of facades (Choi, 1993, 1999; Blocken and Carmeliet, 2004; Foroushani et al., 2014; Derome et al., 2017). The effect of WDR on buildings has long been recognised as a significant maintenance problem and has been linked to damages caused by the penetration of rainwater into the facades of buildings (Choi, 1999). The damage has been mainly related to the increased amount of moisture present in the

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https://doi.org/10.1016/j.ibiod.2018.07.016
Received 10 May 2018; Received in revised form 25 July 2018; Accepted 29 July 2018
0964-8305/

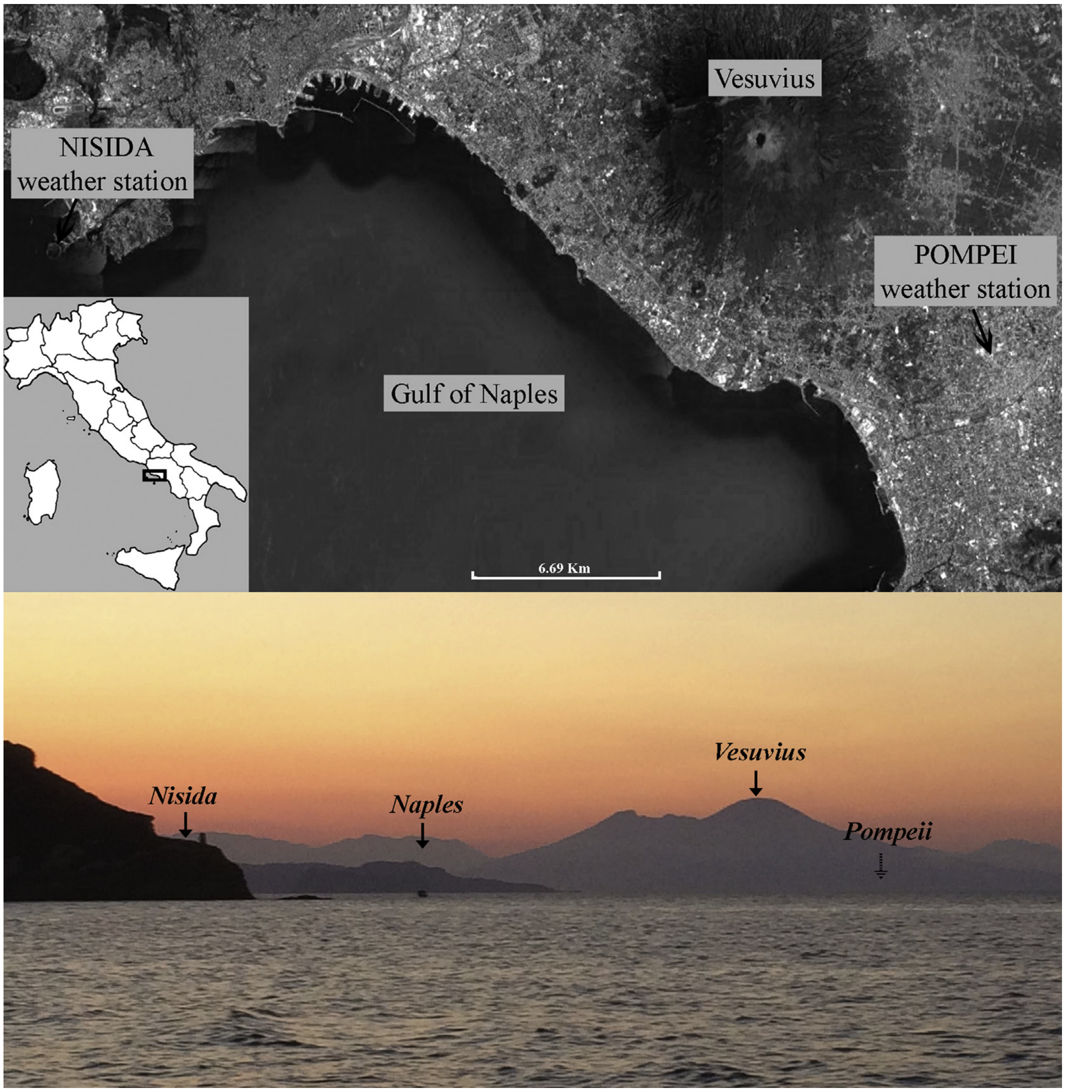

Fig. 1. Study area with the location of the weather stations. Geographic coordinates: Nisida station for wind intensity and direction (40°47′45.25″N; 14°09′47.11″E), Pompeii station for rainfall (40°44′46.70″N; 14°29′56.34″E) bottom: view of the Nisida station with a view of the Gulf (photo G. Caneva).

surfaces and to the consequent loss of colour and the detachment of fragments (Karagiozis et al., 1997; Erkal et al., 2012).

The linkages between bioclimatic conditions and biological colonization have been explored in some contexts. For instance, Gradeci et al. (2018) studied the potential biological growths in façade constructions in relation to microclimatic conditions in Norway where, considering the temperate bioclimate and timber as the building material, they considered mainly moulds as biological communities capable of growth. Under the conditions of vertical surfaces of stone buildings in Rome (Italy) in the absence of other external inputs of water, WDR - referred to as incident rainfall (Danin and Caneva, 1990) - became the main factor controlling the biological growth (BG). Caneva et al. (1992) showed the existence of significant correlations between lithobiont growth and incident rainfall in several buildings in Rome and the surrounding areas. The identified species of colonization were mainly cyanobacteria and, to a lesser extent, lichens (Caneva et al., 1992). Subsequent results confirmed such observations for the embankments of the Tiber River in Rome (Bellinzoni et al., 2003; Caneva et al., 2004), where the potential umbrella effect of trees and edaphic factors were also relevant. A similar microbial colonization on Angkor monuments in Cambodia and Southeast Asian countries was also reported with lichen and cyanobacteria as pioneering communities, followed by heterotrophic bacteria and fungi (Lan et al., 2010; Li et al., 2010; Kusumi et al., 2013; Hu et al., 2013; Meng et al., 2016, 2017), but also mosses, ferns and higher plants depending on lighting and humidity conditions (Caneva et al., 2015, 2016).

Protection of monuments and archaeological sites from WDR can improve their conservation and preservation, but, in the literature, there are only a few assessments of WDR, and information on the effect of WDR on BG is lacking. As a result, we highlight the need to investigate WDR as a potential factor affecting conservation practice in cultural heritage sites. On the basis of our previous experiences in Rome, the archaeological site of Pompeii was selected, considering some similarities on materials and bioclimatic conditions between the two sites, to investigate the conservation of this UNESCO World Heritage site. In fact, Pompeii is an ancient Roman town destroyed in the first Century AD by the eruption of Mount Vesuvius and buried for a long time (Ward-Perkins and Claridge, 1978). Systematic excavations and conservation planning started over the last century, and several studies have been carried out on its archaeological materials (Jashemski and Meyer, 2002; Özgenel, 2008), but little information exists on the environmental conditions (Merello et al., 2014; Maguregui et al., 2012a) and the occurrence of biodeterioration phenomena (Maguregui et al., 2012a; b; Veneranda et al., 2017; Tescari et al., 2018).

The objective of this study is to verify the ecological role of WDR in