

## Original article

Assessing the thermal dampening and blanketing effects of ivy (*Hedera helix*) on stone-built coastal heritage assets under summer conditionsGeorgina Jenkins<sup>a</sup>, Timothy Baxter<sup>b,\*</sup><sup>a</sup> Department of Geography, Durham University, Durham, United Kingdom<sup>b</sup> Pitt Rivers Museum, University of Oxford, Oxford, United Kingdom

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## ABSTRACT

Climbing plants, such as English ivy (*Hedera helix*), are an important component of the natural and built environment, and are increasingly integrated into the designs of modern developments to provide aesthetic and thermal benefits. Yet, the influence of ivy on the conservation of historic buildings remains controversial. In urban and rural settings, ivy has been shown to both enhance and retard material breakdown. However, in dynamic coastal environments, where heritage assets are regularly exposed to variable weather conditions and damaging ocean spray, the impacts of ivy on stone decay are relatively unknown. In this study, a combination of laboratory simulations and field experiments were used to assess the impacts of different covers of ivy (i.e., full foliage, managed foliage, and exposed stone) on surface and subsurface microclimates and stone deterioration at two sixteenth century castles in Kent, UK. Our results show that ivy may shield surfaces against potentially damaging salt crystals, and buffer extremes and fluctuations in temperature and humidity during warm, summer conditions. Importantly, we show that heavily-managed stems can provide protective functions irrespective of leaves through the modulation of environmental variables linked to stone decay.

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## 1. Introduction and research aims

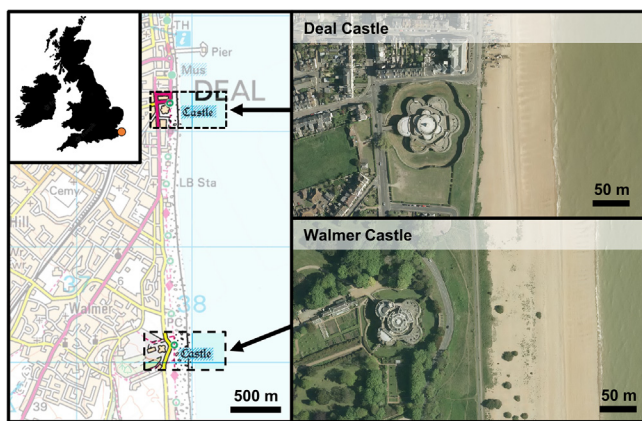
English ivy (*Hedera helix*) grows prolifically on the walls of many historic buildings in the UK and around the world [23]. This includes coastal fortifications built of natural stone, such as castles, blockhouses, and artillery forts [19,43,50,58]. In addition to supporting diverse communities of plants and animals, these highly valued heritage assets provide multiple co-benefits to local communities, economies, and ecosystems, such as flood protection, educational space, and sites of cultural significance [24,42]. Yet, many of these structures are threatened by coastal erosion and associated climate change impacts, such as sea-level rise [30,32,44,47], as well as physical and chemical weathering processes enhanced by frequent exposure to ocean spray, extreme precipitation events (i.e., winter storms), and variable temperature cycles [37–41,57]. In certain cases, vascular plants and other forms of biota, such as lichen and mosses, can exacerbate the deterioration of coastal fortifications and built heritage more generally (e.g., [42,43]). However, this remains controversial, with the protective potential of plants increasing recognised over recent years (e.g., [29,34,56]).

In terrestrial environments, ivy and other canopy forming species have been shown to both enhance and retard material breakdown [16,23,36,52]. When left undisturbed, the roots of ivy may penetrate and weaken pre-existing defects in mortar and stone, causing extensive damage to historic buildings and archaeological sites [3,8,13,22]. However, dense covers of ivy have also been shown to protect surfaces from airborne pollutants [45,49,58], and reduce the efficiency of mechanical and chemical weathering processes through the regulation of near-surface microclimates [18,21,50]. Observed differences in the aggressiveness of ivy and its impacts on material breakdown have been attributed to variations in the bioclimatic and edaphic conditions experienced by plants growing in different locations and environmental settings [9].

While the bioprotective and erosive potential of ivy have been investigated in urban and rural locations, as well as under controlled laboratory conditions [16,18,20,58], few studies have directly examined the impacts of ivy on surface and subsurface microclimates and associated weathering processes in dynamic coastal environments, where historic buildings are regularly exposed to potentially damaging marine aerosols (*Supplementary Material, S1*). Under these conditions, dense covers of ivy may provide valuable protection against salt crystallisation and extremes

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**Fig. 1.** The location of the field sites at Deal Castle and Walmer Castle (© Crown copyright and database rights 2022 Ordnance Survey). Aerial photographs accessed from the Channel Coast Observatory ([coastalmonitoring.org](http://coastalmonitoring.org)).

in temperature and humidity that facilitate processes of stone decay. Furthermore, there is limited understanding of whether the surface-cooling effects associated with ivy persist once foliage has been removed from stems due to pruning or similar management practices [10].

In this study, we use a combination of field experiments and laboratory simulations to investigate the protective potential of different covers of ivy (i.e., full foliage vs. managed foliage vs. no foliage) on two sixteenth-century forts on the south coast of England, UK. In doing so, we aim to contribute valuable research-based evidence to help inform future management practices and resilience-planning efforts at coastal heritage sites.

## 2. Material and methods

### 2.1. Study site and field experiment

Over a two-week period in July 2022, field experiments were conducted on the walls of two sixteenth-century artillery forts on the south coast of England: Deal Castle (51°13'10" N, 1°24'13" E) and Walmer Castle (51°12'02" N, 1°24'07" E). Both castles are constructed of limestone (Kentish ragstone) and are managed by English Heritage as Scheduled Monuments. Located approximately 2 km apart, both castles are within 150 m of the coastline (Fig. 1).

Met Office climate data collected at Dover Harbour between 1991 and 2020 shows that average summer (June–August) temperatures ranged between 12–21 °C along this stretch of coastline. In contrast, average winter (December–February) temperatures ranged between 3 and 8 °C. Annual rainfall was approximately 832 mm, and there were on average 43 days of frost per year. At both sites, wind blows predominantly onshore in a southwesterly direction.

At each site, microclimate data (i.e., near-surface temperature and humidity) and data on two different indicators of weathering and material breakdown (i.e., surface hardness and roughness) were collected on sections of wall comparable in age, material, aspect (i.e., east- or northeast-facing), and environmental setting. Both study walls had significant covers of ivy (i.e., 95 % coverage), however the types of cover varied between the two sites (Fig. 2). At Deal Castle, the ivy had been left undisturbed for at least a decade and was up to 30 cm thick (i.e., full foliage), with an estimated Leaf Area Index (LAI) of over 0.95 in covered areas. In contrast, many years of management and pruning had left the ivy at Walmer Castle with limited foliage (LAI < 0.05), although a dense network of stems remained on the stone surfaces (i.e., managed foliage). The distinct conditions found at these sites provided a unique opportunity to compare how different covers of ivy and

associated management strategies influence near-surface microclimate regimes and weathering processes on stone-built heritage assets in a coastal setting.

At each study wall, measurements were taken on twenty 25 × 25 cm plots: ten areas with significant (95 %) ivy cover (i.e., full foliage or managed) and ten areas of bare substrate with no evidence of ivy cover for at least 10 years. These two treatments are hereafter referred to as 'ivy-covered plots' and 'bare plots', respectively. On each wall, plots with the same treatment (i.e., ivy-covered and bare) were spaced at 50 cm intervals along a vertical transect.

### 2.2. Temperature and humidity regimes

Three temperature and humidity loggers (Maxim® DS1923 iButton Thermochrons) were placed in bare and ivy-covered plots at each site. At Deal Castle the loggers were placed under ivy cover between 25 and 30 cm thick, while at Walmer Castle the loggers were placed under leafless stems approximately 2–3 cm thick. The loggers were pre-programmed to measure near-surface rock temperature (°C) and relative humidity (RH, %) at 10-min intervals. Temperature data were collected at both sites between 7th and 19th July 2022, whereas RH data were collected between 11th and 19th July 2022. At the end of the monitoring periods, the data were downloaded using a Blue-Dot iButton® reader (Maxim Integrated Products) and OneWireViewer software (Maxim Integrated Products). The loggers have an operating range of –30 to 70 °C, resolution of 0.5 °C, and accuracy of ± 0.5 °C. The same devices have previously been used in weathering studies to determine the influence of ivy and other canopy-forming species on rock-surface thermal regimes (e.g., [4,28,50]). Time-series data of near-surface temperature and RH for both the bare and ivy-covered plots were averaged for each site and compared graphically. Descriptive statistics (maximum, minimum, and range) were also calculated and compared between the covered and bare plots.

In addition to the environmental loggers, an infrared camera was used to collect thermal images of bare and ivy-covered surfaces at each site. Thermal imagery has previously been used to assess the influence of ivy cover and other types of vertical greenery on near-surface temperature regimes on experimental test walls constructed of limestone and brick [10,18]. In this study, infrared images were recorded using a Teledyne FLIR C3-X thermal camera at 30-min intervals over a 6-hr time period (10:30 to 16:30) on 8th July 2022 at Deal Castle and 11th July 2022 at Walmer Castle. These images were subsequently downloaded and analysed using the software FLIR Tools. Visual comparisons were made to determine differences in the thermal characteristics of the covered and exposed sections of the walls. The thermal camera can measure the temperature of objects between –10 to 150 °C with an accuracy of ± 2 °C. Although the emissivity of stone, leaves, and stems is unlikely to be equal, a general emissivity value of 0.95 was used in accordance with standards adopted in previous studies [1,5,14,33]. Thermal data recorded using the infrared camera was found to be broadly consistent (i.e., ± 3 °C) with direct measurements collected using the iButtons. Variations in the thermal reflection/ emissivity of different surfaces were therefore considered to have had limited impact on the overall results.

### 2.3. Rock surface hardness

Surface hardness data were collected at each site using an Equotip Piccolo 2 (D-type). The Equotip expresses hardness as a 'Leeb' value (HL) and has a resolution of 1 HL and an accuracy of ±4 HL. HL is a comparative rock hardness unit calculated using the ratio of the rebound velocity to the impact velocity of a hard indenter sphere fired by the tool at a surface [59]. The Equotip has



**Fig. 2.** The sections of wall and patches of ivy studied at Deal Castle (left) and Walmer Castle (right). Both walls are orientated towards the northeast, and are comparable in age, material, and design.

been widely used to measure rock-surface hardness as a way of determining the degree of weathering a surface has experienced over time (e.g., [2,6,15,54,59]). At each plot (ivy-covered and bare), 30 Equotip measurements were taken using the single impact method [55]. Care was taken when using the Equotip to ensure that the base of the device was positioned on a flat surface and away from any ledges to reduce the impact of edge effects [55]. Before use, the Equotip was calibrated using a calibration block. Each set of 30 measurements was averaged, to create a single value of hardness (HL) for each plot.

#### 2.4. Rock surface roughness

A profile gauge with 1 mm diameter movable pins was used to quantify the surface roughness of each plot as an indicator of material breakdown. This method has been widely used in geomorphology and engineering to derive profile-based topographic information and assess surface decay (e.g., [6,25,27,35]). Three profiles were collected for each plot and then traced onto paper before being photographed and digitised using the free online tool WebPlot-Digitizer. XY coordinate data were then extracted from each profile and imported into Microsoft Excel. The arithmetic roughness ( $R_a$ ) of each profile was then calculated and averaged across the three measurements to create a single value of  $R_a$  for each plot. In this instance,  $R_a$  represents the average deviation of 1-mm-spaced points (XY coordinates) compared to the mean height of a surface over a 25 cm sampling length [26].

#### 2.5. Salt crystallisation and rooting

To determine whether ivy can act as a physical barrier against airborne salts, a wireless digital microscope (SKYBASIC) was used to collect 50x magnified images of the surface of each plot. In addition, magnified images of the ivy canopy were collected at Deal Castle to assess for evidence of salt deposition on the leaves. Similar techniques have previously been used to assess the ability of ivy to trap particulate pollution in urban environments (e.g., [49]). A visual inspection of both walls was also conducted to assess for evidence of rooting and other potentially damaging impacts caused by the colonising ivy.

#### 2.6. Laboratory simulations

To complement the near-surface temperature measurements collected in the field, laboratory simulations were used to record the influence of ivy cover on the internal (subsurface) temperature of stone [4,17,28]. Six sample blocks (6 × 6 × 5 cm) of limestone

were cut from pre-weathered material. The upper surfaces of three of the blocks were draped in freshly cut ivy to simulate a covered plot (Fig. 3). The remaining three blocks were left uncovered to simulate a bare plot. In order to monitor subsurface temperature gradients, each block had 3- and 4-cm-deep holes (each 3.175-mm-wide) drilled into its underside for the insertion of thermal probes. These holes were positioned equidistant from the edges of the samples. Two flexible lead thermistor probes (PB-5009-0 M6, Gemini Co., UK) connected to a Tiny Tag Plus 2 temperature logger (TGP-4520, Gemini Co., UK) were inserted into the prepared holes allowing temperatures to be recorded at 1 cm and 2 cm depths from the surfaces of the samples [4].

The sample blocks were then placed into a styrofoam mould in an attempt to limit heat exchange to the upper surface [12,17] and positioned inside an environmental chamber (Sanyo-FE 300H) under a lamp with a full-spectrum daylight bulb which was included to better simulate the warming of stone via insolation [4,28,48,53]. In addition to the thermistor probes, an environmental sensor (Maxim ® DS1921G iButton Thermochron) was used to record temperatures on the upper surface of each block.

The environmental chamber was programmed to simulate conditions representative of a ‘model summer’s day’ on the south coast of England based on meteorological data collected from a weather station at Deal Pier [4]. To simulate these conditions, the environmental chamber was programmed to cycle between 15 °C and 30 °C over a 12-h period. The cycle was repeated five times, with the same blocks used throughout the experiment. During the cycles, thermistor probes were used to measure the subsurface (1-cm and 2-cm depths) temperatures of the blocks at 2-min intervals. Before each cycle, fresh ivy was applied to the ivy-covered blocks. The upper surfaces of the sample blocks were also sprayed with a sea salt solution (34 g NaCl / 1 L water) to simulate ocean spray. After each cycle, the sample blocks were left to cool for at least two hours so they could reach an equilibrium temperature. Data collected using the thermistor probes were downloaded and averaged for each treatment (i.e., covered vs. bare). The internal temperature regimes of the ivy-covered blocks and bare blocks were then compared using graphical representations and descriptive statistics.

#### 2.7. Statistical analysis

Two sample *t*-tests were used to compare differences in surface hardness (mean HL) and surface roughness (mean  $R_a$ ) between the ivy-covered plots and bare plots monitored in the field. In all instances, assumptions for parametric tests were checked beforehand, and normality requirements were met. All statistics tests were performed using the software R (version 4.2.2).



Fig. 3. The experimental setup used for the laboratory simulations.

Table 1

Daily minimum ( $T_{\min}$ ), maximum ( $T_{\max}$ ), and range in near-surface temperature at the ivy-covered and bare plots at Deal Castle and Walmer Castle. The mean daily maximum temperature difference between ivy-covered plots and bare plots at each site is also shown.

Location	Mean daily minimum temperature ( $T_{\min}$ , °C)		Mean daily maximum temperature ( $T_{\max}$ , °C)		Mean daily temperature range ( $T_{\text{range}}$ , °C)		Mean daily maximum temperature difference ( $T_{\text{diff}}$ , °C)
	Covered	Bare	Covered	Bare	Covered	Bare	
Deal Castle (Full foliage)	18.63	17.41	22.41	27.83	3.78	10.41	5.70
Walmer Castle (Managed foliage)	21.41	19.96	31.69	38.07	10.28	18.11	5.68

### 3. Results

#### 3.1. Near-surface temperature

At both sites, the mean daily maximum temperature ( $T_{\max}$ ) and range ( $T_{\text{range}}$ ) were consistently lower in the ivy-covered plots compared to the bare plots (Table 1 and Fig. 4). Daily minimum temperatures ( $T_{\min}$ ) were also consistently higher in the ivy-covered plots compared to the bare plots. Over the entire monitoring period, the highest temperature (43.39 °C) was recorded in a bare plot at Walmer Castle, while the lowest temperature (15.08 °C) was recorded in a bare plot at Deal Castle.

The mean daily maximum temperature difference between ivy-covered plots and bare plots ( $T_{\text{diff}}$ ) at Deal Castle and Walmer Castle was 5.70 and 5.68 °C, respectively (Table 1). The greatest temperature differences were typically recorded at both sites in the morning and early-afternoon between 08:30 and 13:00. Across the entire monitoring period, the greatest  $T_{\text{diff}}$  (10.08 °C) was recorded at Walmer Castle on 16th July 2022 at 11:35 am (Fig. 4).

At Deal Castle, the greatest increase in temperature over a 1-minute time period ( $T_{1-\text{min}}$ ) was 0.75 °C for the ivy-covered plots and 2.34 °C for the bare plots. At Walmer Castle,  $T_{1-\text{min}}$  was 2.34 °C for the ivy-covered plots and 4.33 °C for the bare plots.

#### 3.2. Infrared imagery

Infrared images show differences in the daily temperature regimes of the study walls at Deal Castle and Walmer Castle (Fig. 5). Surfaces covered with ivy remained consistently cooler than areas with no ivy cover throughout the monitoring periods. At Walmer Castle, high temperatures (> 40 °C) were recorded on ivy stems during the warmest part of the day (10:30 am). However, areas of wall under/adjacent to these stems appear to have remained relatively cool compared to areas of exposed stone.

#### 3.3. Relative humidity

Time-series data of average RH at Deal Castle and Walmer Castle are shown in Fig. 6. At Deal Castle, RH was consistently higher in the ivy-covered plots compared to the bare plots (Table 2). In contrast, at Walmer Castle, the bare plots experienced the greatest extremes in RH throughout the monitoring period. At both sites, the daily range in RH was consistently higher at the bare plots compared to the ivy-covered plots.

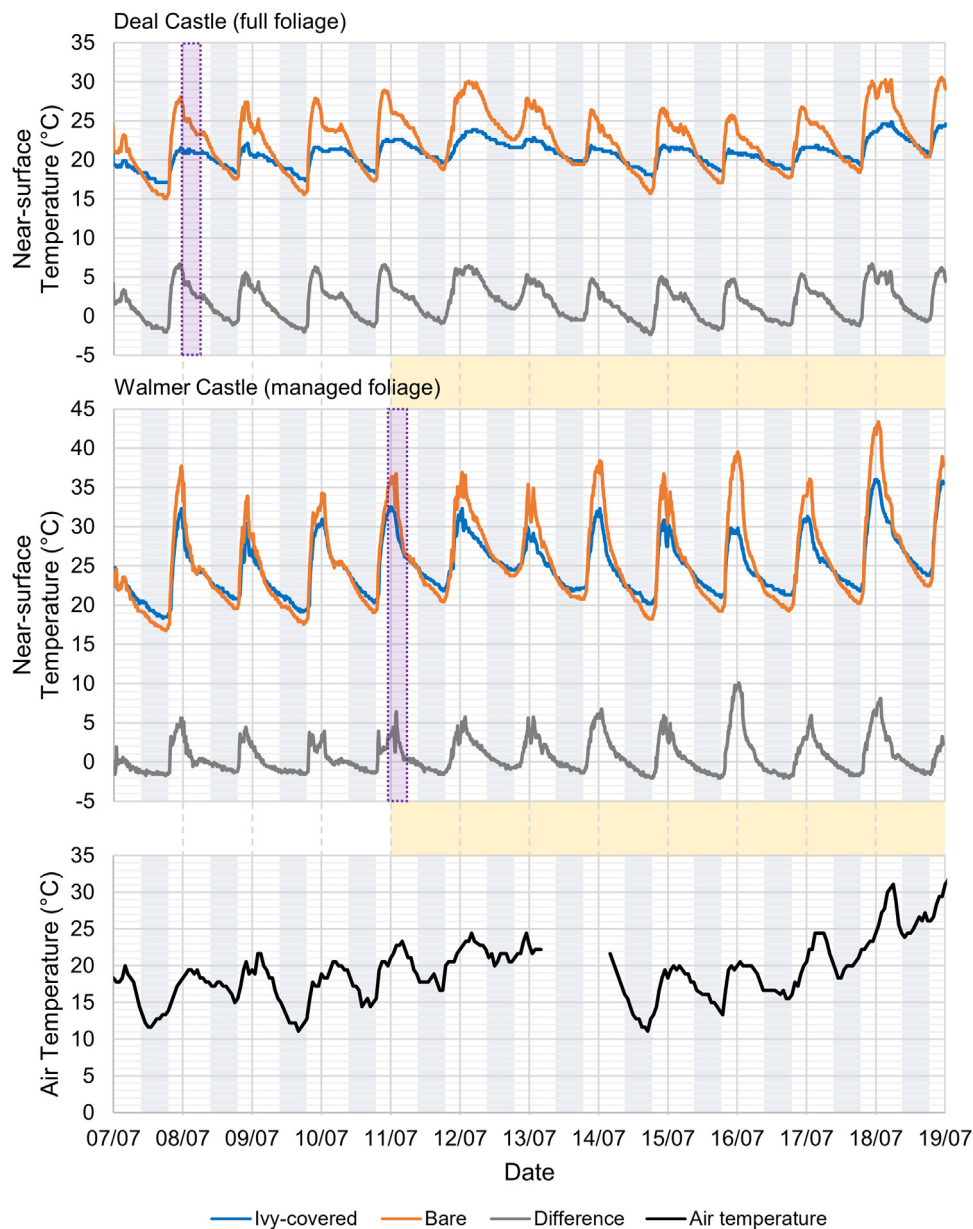
#### 3.4. Sub-surface temperature regimes

The subsurface temperature regimes at 1 cm and 2 cm depths were consistently lower in the ivy-covered samples compared to the bare samples during the laboratory simulations (Fig. 7). Temperature differences between the two conditions (i.e., covered vs. bare) were generally greater at 1 cm depths than at 2 cm depths. Temperature data collected from the surfaces of the sample blocks also reveal that surface temperatures on the ivy-covered blocks were lower during the warming phase of the cycle (i.e., 0 to 360 mins) but higher during the cooling phase of the cycle (i.e., 360 to 720 mins; Supplementary Material, S2).

#### 3.5. Surface hardness and roughness

At both Deal Castle and Walmer Castle, no significant difference in surface hardness was found between the ivy-covered plots and the bare plots (Deal:  $t(9) = 1.351$ ,  $p = 0.196$ , Walmer:  $t(9) = 0.290$ ,  $p = 0.776$ ) (Fig. 8). At Deal Castle, the mean surface hardness in the ivy-covered plots and bare plots was 246.34 and 260.29 HL, respectively. In comparison, at Walmer Castle, the mean surface hardness was 305.87 HL in the ivy-covered plots and 308.78 HL in the bare plots.

T-tests also showed no significant difference in mean surface roughness between the ivy-covered plots and bare plots at both



**Fig. 4.** First (Deal Castle) and second (Walmer Castle) rows: Average near-surface temperatures ( °C) recorded at 10-min intervals at ivy-covered plots (blue line) and bare plots (orange line), and the difference between the two conditions (grey line). Third row: Air temperature recorded at the Met Office weather station at Dover Harbour, roughly 12 km from the study sites. Periods of daylight (05:00 to 21:00 BST) and darkness (21:00 to 05:00 BST) are shown as white and grey bands, respectively. The purple boxes indicate when infrared images were recorded (see Fig. 5), while the yellow bands indicate when humidity data was collected (see Fig. 6). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 2**  
Daily minimum ( $T_{min}$ ), maximum ( $T_{max}$ ), and range in relative humidity at the ivy-covered and bare plots at Deal Castle and Walmer Castle.

Location	Mean daily minimum relative humidity ( $RH_{min}$ , %)		Mean daily maximum relative humidity ( $RH_{max}$ , %)		Mean daily range ( $RH_{range}$ , %)	
	Covered	Bare	Covered	Bare	Covered	Bare
Deal Castle (Full foliage)	69.60	49.88	83.87	82.80	14.27	32.92
Walmer Castle (Managed foliage)	38.02	26.44	66.87	75.09	28.85	48.66

sites (Deal:  $t(9) = -0.852$ ,  $p = 0.406$ , Walmer:  $t(9) = -1.889$ ,  $p = 0.078$ ) (Fig. 8). At Deal Castle, the mean surface roughness in the ivy-covered plots and bare plots was 0.43 cm and 0.38 cm, respectively. In comparison, at Walmer Castle, the mean surface roughness was 0.34 cm in the ivy-covered plots and 0.26 cm in the bare plots.

### 3.6. Airborne salt particles

At Deal Castle, 50x magnified images revealed the potential formation of salt crystals on the outer surfaces of ivy leaves (Supplementary Material, S3). In contrast, there was limited evidence of salt crystals on the inner (wall facing) surfaces of the leaves or on

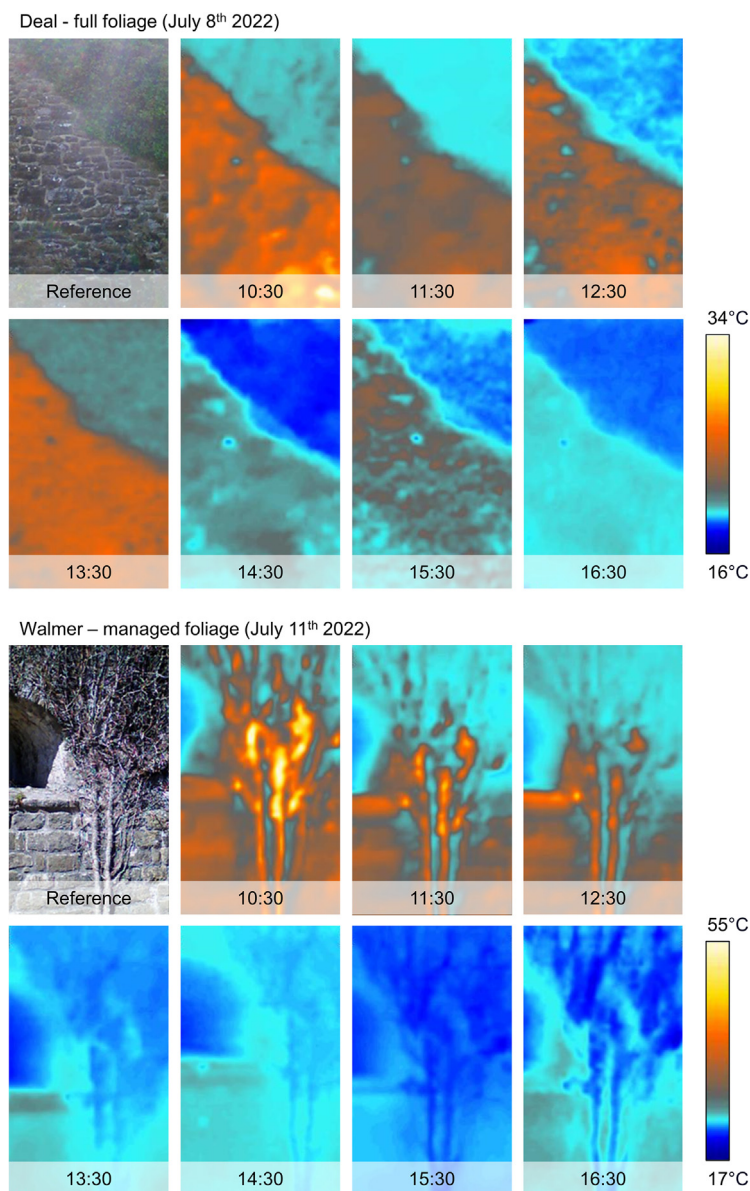


Fig. 5. Thermal imagery showing the surface temperature ( °C) of the study walls at Deal Castle and Walmer Castle.

underlying stone at this site. Salt crystals, similar in size and appearance to the deposits identified in the field, were also observed on the ivy leaves used in the laboratory experiment after they had been exposed to a simulated summer cycle.

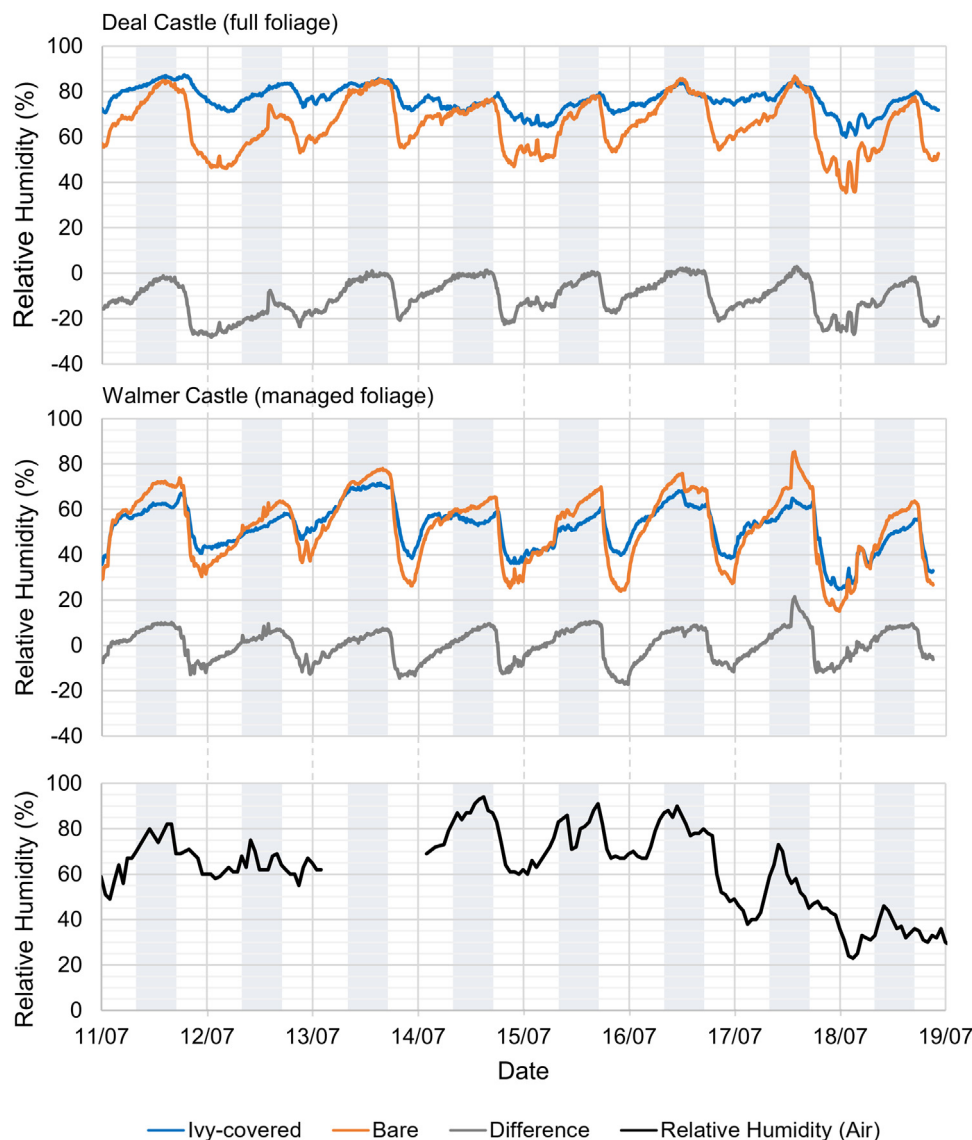
#### 4. Discussion

##### 4.1. Influence of ivy on near-surfaces microclimates

Daily temperature extremes and fluctuations were significantly dampened on surfaces covered with ivy relative to adjacent areas of exposed stone at both Deal Castle and Walmer Castle. During warm weather (i.e., air temperatures greater than 20 °C), temperatures were reduced by more than 5 °C on surfaces with thick covers of ivy (i.e., Deal Castle) as well as those with limited foliage (i.e., Walmer Castle). The presence of ivy was also found to increase surface temperatures during the coldest part of the day, with mean daily minimum temperatures approximately 7 % greater under ivy cover at both sites (Fig. 4). These findings are consistent with those of previous studies that have highlighted

the potential for ivy to modulate near-surface temperatures during both warm and cold conditions in temperate environments (e.g., [7,16,18,50,58]). Coombes et al. [18], for example, reported similar surface-cooling effects during peak summer conditions (i.e., July) in Oxfordshire, UK, for a test wall comparable in construction (i.e., limestone), aspect (i.e., east- and north-facing), and canopy thickness (i.e., 20–30 cm) to the study wall at Deal. In contrast, more pronounced thermal effects have been reported for canopies with greater thicknesses (e.g., [58]), including on an east-facing revetment wall in Dover, UK, less than 12 km from the study sites, where surface temperatures were reduced by up to 17 °C under covers more than 90 cm thick [50].

In this study, surface-cooling effects observed in the field were found to translate to reductions in the internal temperature of stone under controlled laboratory conditions, with temperatures at 1 and 2 cm depths significantly reduced under ivy cover (5–10 cm thick). Such thermal effects have been shown to influence rates of deterioration on surfaces covered by ivy and other canopy-forming species, such as seaweed, with increased cover generally associated with reduced rates of material breakdown [16,28]. The results



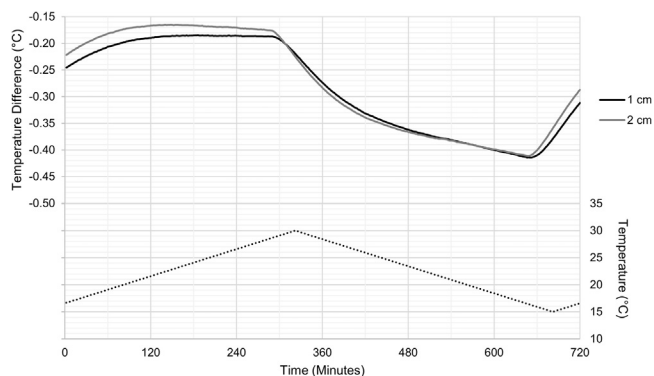
**Fig. 6.** First (Deal Castle) and second (Walmer Castle) rows: Average relative humidity (%) recorded at 10-min intervals at ivy-covered plots (blue line) and bare plots (orange line), and the difference between the two conditions (grey line). Third row: Relative humidity recorded at the Met Office weather station at Dover Harbour, roughly 12 km from the study sites. Periods of daylight (05:00 to 21:00 BST) and darkness (21:00 to 05:00 BST) are shown as white and grey bands, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

presented here thus support the notion that ivy can limit the efficiency of weathering processes associated with vertical temperature gradients and repeated thermal cycling, such as thermal fatigue, although further research is required to develop a causal link between internal cooling and rates of stone decay under different cover types.

Surface and subsurface cooling by ivy is caused by direct shielding from insolation and localised cooling via evapotranspiration [18]. Such thermal effects are influenced by a combination of factors such as aspect, canopy thickness, and substrate type, with cooling generally enhanced on south-facing walls and those with thicker covers (e.g., [50,58]). However, in this study, leafless stems associated with heavily managed and/or excised plants were also found to buffer thermal extremes during warm, summer conditions, with temperatures reduced by up to 10 °C under stems at Walmer Castle relative to exposed stone. As previously noted by Cameron et al. [10], a dense network of stems may contribute to surface-cooling by increasing shade and acting as a conduit for cool soil water. Daily ranges in RH were also found to

be dampened under stems at Walmer Castle, further indicating that ivy can regulate near-surface microclimates irrespective of leaves.

At Deal Castle, diurnal ranges in RH were also dampened on surfaces covered by ivy, although RH was generally higher under ivy cover than on bare stone. Across the entire monitoring period, ivy cover was found to increase RH on surfaces at Deal Castle by an average of 10.79% and a maximum of 28.15%, with the greatest differences observed during the warmest parts of the day. These values broadly correspond to those previously reported in studies investigating the impact of ivy on near-surface microclimates, with typical values ranging between 10–20% for dense covers of foliage (e.g., [21,50,51]). During warm summer conditions, this effect is thought to be largely driven by evapotranspiration, which is enhanced with increasing sunshine and temperature [51]. Differences in RH recorded at Walmer Castle and Deal Castle are therefore likely the result of variations in leaf cover between the two sites and associated differences in shading and evapotranspiration rates [51].



**Fig. 7.** Temperature difference ( °C) between ivy-covered blocks and bare blocks at 1 cm (black line) and 2 cm (grey line) depths averaged across five, 12 h cycles simulating a ‘model summer’s day’ (dashed line).

#### 4.2. Implications for weathering and stone deterioration

Although ivy has been shown to damage heritage sites (e.g., [3,8,13,16,22]), a thorough inspection of the study walls at Deal and Walmer Castle revealed limited evidence of rooting and other forms of biodeterioration. This assessment is supported by the hardness and roughness data, which showed no significant difference between surfaces covered with ivy and adjacent areas of exposed stone, indicating that ivy had, at worst, a negligible impact on stone decay at the two sites [6]. Instead, our findings suggest that ivy may protect against certain forms of deterioration by reducing surface and sub-surface extremes and fluctuations in temperature and RH in temperate summer conditions, thereby limiting the potential for damaging weathering processes caused by the repeated heating-cooling and expansion-contraction of construction materials [18]. Reductions in the extent and frequency of drying may also reduce the likelihood of salt crystallisation on underlying surfaces. Deterioration due to salt weathering is likely further reduced by ivy acting as a shield against potentially damaging marine aerosols, as demonstrated at Deal Castle. This finding complements previous observations of ivy providing a protective barrier against wind-driven rain [23,58] and particulate pollution linked to the physical, chemical, and aesthetic degradation of vulnerable stone [45,49]. In the context of climate change and associated increases in global air temperatures, the thermal effects of ivy may become increasingly important for modulating temperature and humidity driven weathering processes at heritage sites, although associated benefits will also depend on the response of ivy to changing environmental conditions and associated management practices [57].

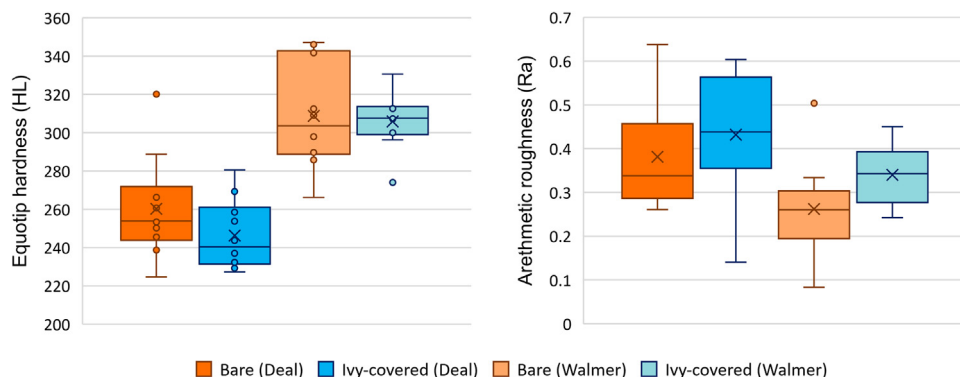
Although our results indicate that ivy may protect underlying stone from temperature-driven modes of breakdown during warm summer conditions, it is uncertain whether these effects persist throughout the year. Variations in bioclimatic and environmental conditions are known to influence the aggressiveness of ivy and its impacts on stone decay [9]. During cold (damp) winter conditions, thermal dampening may reduce the frequency and duration of damaging frost events on covered stone (e.g., [18,51]). Alternatively, frost damage may be enhanced due to increases in RH and moisture typically found under ivy cover. Managers responsible for protecting coastal heritage sites should consider how seasonal variations in weather and climate may influence the growth of ivy as well as the indirect impacts it may have on vulnerable surfaces.

#### 4.3. Wider implications

In addition to providing protection against certain forms of deterioration, dense covers of ivy may also influence the internal environment of historic buildings [16,31]. Although not directly investigated here, previous assessments have shown that ivy and other types of vertical greenery can buffer extremes and fluctuations in the internal temperature and RH of buildings during both warm (summer) and cold (winter) conditions (e.g., [7,46,51]). Due to the thickness of the walls (i.e., > 1 m), the impact of ivy on the internal environments of Deal and Walmer Castle is likely negligible. However, it is conceivable that dense covers of ivy may regulate the internal conditions of other coastal heritage sites, especially those with thinner walls and/or constructed of bricks and mortar. Through the modulation of internal temperatures ivy may reduce building energy consumption and related costs, and contribute to climate change mitigation and adaptation at these sites [7,11,21]. Such thermal effects may also reduce costs associated with the repair and restoration of valuable artifacts stored within historical buildings that are sensitive to changes in environmental conditions, such as paintings, furniture, and tapestries.

### 5. Conclusions

The findings presented in this study contribute to a growing body of evidence highlighting the protective potential of ivy on historic buildings in a variety of environmental settings. Although ivy can be undeniably damaging in some cases, the results of this study indicate that it may also protect surfaces from extremes and fluctuations in temperature and RH and act as a barrier against potentially damaging salt crystals. Microclimate regulation by ivy is known to be influenced by canopy thickness, with surface-cooling effects generally enhanced with increased foliage. However, as shown in this study, the protective potential of heavily managed stems should not be overlooked, with excised stems shown to



**Fig. 8.** The surface hardness (HL, right) and surface roughness (m, left) of ivy-covered plots (blue) and bare plots (orange) at Deal Castle and Walmer Castle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

provide comparable surface-cooling effects to leafy plants during warm, summer conditions. When determining how best to manage ivy at coastal heritage sites, it is important that managers consider the full spectrum of bioprotective and bioerosive properties associated with ivy in its various conditions and different stages of growth. Future research should seek to determine the protective and/or erosive potential of other plants found growing on coastal heritage sites, including those uniquely adapted to coastal environments that have received limited attention elsewhere.

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### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.culher.2025.11.014](https://doi.org/10.1016/j.culher.2025.11.014).

### References

- [1] M.A. Aguilera, R.M. Arias, T. Manzur, Mapping microhabitat thermal patterns in artificial breakwaters: alteration of intertidal biodiversity by higher rock temperature, *Ecol. Evol.* 9 (22) (2019) 12915–12927.
- [2] H. Aoki, Y. Matsukura, Effects of rock strength and location heights on growth rates of tafoni-like depressions at sandstone blocks used for a masonry bridge pier in the coastal spray zone, *Z. Geomorphol.* 51 (2007) 115–132.
- [3] F. Bartoli, F. Romiti, G. Caneva, Aggressiveness of *Hedera helix* L. growing on monuments: evaluation in Roman archaeological sites and guidelines for a general methodological approach, *Plant Biosyst.* 151 (5) (2017) 866–877.
- [4] T.I. Baxter, M.A. Coombes, H.A. Viles, The bioprotective properties of the blue mussel (*Mytilus edulis*) on intertidal rocky shore platforms, *Mar. Geol.* 445 (2022) 106734 1–12.
- [5] T.I. Baxter, M.A. Coombes, H.A. Viles, Intertidal biodiversity and physical habitat complexity on historic masonry walls: a comparison with modern concrete infrastructure and natural rocky cliffs, *Mar. Pollut. Bull.* 188 (2023) 114617.
- [6] T.I. Baxter, M.A. Coombes, H.A. Viles, No evidence that seaweed cover enhances the deterioration of natural cement-based mortar in intertidal environments, *Earth. Surf. Process. Landf.* 47 (15) (2023) 3453–3464.
- [7] C. Bolton, M.A. Rahman, D. Armson, A.R. Ennos, Effectiveness of an ivy covering at insulating a building against the cold in Manchester, UK: a preliminary investigation, *Build. Environ.* 80 (2014) 32–35.
- [8] G. Caneva, A. Roccardi, Harmful flora in the conservation of Roman monuments, in: *Biodeterioration of Cultural Property: Proceedings of the International Conference on Biodeterioration of Cultural Property*, February 2025, 1989, Delhi, Macmillan, India, 1991.
- [9] G. Caneva, Z. Hosseini, F. Bartoli, Risk, hazard, and vulnerability for stone biodeterioration due to higher plants: the methodological proposal of a multifactorial index (RHV), *J. Cult. Herit.* 62 (2023) 217–229.
- [10] R.W. Cameron, J.E. Taylor, M.R. Emmett, What's 'cool' in the world of green façades? How plant choice influences the cooling properties of green walls, *Build. Environ.* 73 (2014) 198–207.
- [11] R.W. Cameron, J.E. Taylor, M.R. Emmett, A *Hedera* green façade—energy performance and saving under different maritime-temperate, winter weather conditions, *Build. Environ.* 92 (2015) 111–121.
- [12] N.E.A. Carter, H.A. Viles, Experimental investigations into the interactions between moisture, rock surface temperatures and an epilithic lichen cover in the bioprotection of limestone, *Build. Environ.* 38 (9–10) (2003) 1225–1234.
- [13] L. Celesti-Grapow, C. Blasi, The role of alien and native weeds in the deterioration of archaeological remains in Italy, *Weed Technol.* 18 (3) (2004) 1508–1513.
- [14] C. Chapperon, L. Seuront, Keeping warm in the cold: on the thermal benefits of aggregation behaviour in an intertidal ectotherm, *J. Therm. Biol.* 37 (8) (2012) 640–647.
- [15] M.A. Coombes, A. Feal-Pérez, L.A. Naylor, K. Wilhelm, A non-destructive tool for detecting changes in the hardness of engineering materials: application of the Equotip durometer in the coastal zone, *Eng. Geol.* 167 (2013) 14–19.
- [16] M.A. Coombes, H.A. Viles, A. Cathersides, Ivy on Walls, 2017 Historic England Research Reports Series no. 30/2017 ISSN 20594453.
- [17] M.A. Coombes, H.A. Viles, L.A. Naylor, E.C. La Marca, Cool barnacles: do common biogenic structures enhance or retard rates of deterioration of intertidal rocks and concrete? *Sci. Total Environ.* 580 (2017) 1034–1045.
- [18] M.A. Coombes, H.A. Viles, H. Zhang, Thermal blanketing by ivy (*Hedera helix* L.) can protect building stone from damaging frosts, *Sci. Rep.* 8 (1) (2018) 1–11.
- [19] A. Cozzolino, R. Motti, I. Vitasović-Kosić, Vascular flora on Croatian historic structures: drivers of biodeterioration and conservation implications, *Plants* 14 (12) (2025) 1773.
- [20] M. De Groeve, E. Kale, S.A. Orr, T. De Kock, Preliminary experimental laboratory methods to analyse the insulation capacity of vertical greening on temperature and relative humidity, *Sustainability* 15 (15) (2023) 11758.
- [21] H.F. Di, D.N. Wang, Cooling effect of ivy on a wall, *Exp. Heat Transf.* 12 (3) (1999) 235–245.
- [22] Z.K. Elinç, T. Korkut, L.G. Kaya, *Hedera helix* L. and damages in Tlos Ancient City, *Int. J. Develop. Sustain.* 2 (1) (2013) 333–346.
- [23] English Heritage Ivey on Walls, Seminar Report, English Heritage, Swindon, UK, 2010.
- [24] A. Firth, Social and Economic Benefits of Marine and Maritime Cultural Heritage, Fjordr Ltd for Honor Frost Foundation, London, 2015.
- [25] J.J. Fornós, L. Gómez-Pujol, J. Cifre, F. Hierro, First steps in limestone weathering and erosion: an atomic force microscopy (AFM) and scanning electron microscopy (SEM) approach, *Acta Carsol.* 40 (2) (2011) 275–282.
- [26] E.S. Gadelmawla, M.M. Koura, T.M. Maksoud, I.M. Elewa, H.H. Soliman, Roughness parameters, *J. Mater. Process. Technol.* 123 (1) (2002) 133–145.
- [27] L. Gómez-Pujol, J.J. Fornós, J.O. Swantesson, Rock surface millimetre-scale roughness and weathering of supratidal Mallorca carbonate coasts (Balearic Islands), *Earth. Surf. Process. Landf.* 31 (14) (2006) 1792–1801.
- [28] M.R. Gowell, M.A. Coombes, H.A. Viles, Rock-protecting seaweed? Experimental evidence of bioprotection in the intertidal zone, *Earth. Surf. Process. Landf.* 40 (10) (2015) 1364–1370.
- [29] S.V. Hanssen, H.A. Viles, Can plants keep ruins dry? A quantitative assessment of the effect of soft capping on rainwater flows over ruined walls, *Ecol. Eng.* 71 (2014) 173–179.
- [30] D.V. Harkin, M. Davies, E. Hyslop, H. Fluck, M. Wiggins, O. Merritt, L. Barker, M. Deery, R. McNeary, K. Westley, Impacts of climate change on cultural heritage, in: *MCCIP Science Review 2020, 2020*, pp. 616–641.
- [31] D. Holm, Thermal improvement by means of leaf cover on external walls—a simulation model, *Energy Build.* 14 (1) (1989) 19–30.
- [32] A. Hunt, English Heritage Oastal Estate: Risk Assessment, English Heritage, Swindon, UK, 2011 Research Department Report Series no. 68–2011.
- [33] J.A. Lathlean, L. Seuront, T.P. Ng, On the edge: the use of infrared thermography in monitoring responses of intertidal organisms to heat stress, *Ecol. Indic.* 81 (2017) 567–577.
- [34] X. Liu, Y. Qian, F. Wu, Y. Wang, W. Wang, J.D. Gu, Biofilms on stone monuments: biodeterioration or bioprotection? *Trends. Microbiol.* 30 (9) (2022) 816–819.
- [35] D. McCarroll, A. Nesje, Rock surface roughness as an indicator of degree of rock surface weathering, *Earth. Surf. Process. Landf.* 21 (10) (1996) 963–977.
- [36] A.K. Mishra, K.K. Jain, K.L. Garg, Role of higher plants in the deterioration of historic buildings, *Sci. Total Environ.* 167 (1–3) (1995) 375–392.
- [37] H. Morillas, F. Franca de Mendonça Filho, H. Derluyn, M. Maguregui, D. Grégoire, J.M. Madariaga, Decay processes in buildings close to the sea induced by marine aerosol: salt depositions inside construction materials, *Sci. Total Environ.* 721 (2020) 137687 1–9.
- [38] D.N. Mottershead, A morphological study of greenschist weathering on dated coastal structures, South Devon, UK, *Earth Surf. Process. Landf.* 22 (5) (1997) 491–506.
- [39] D.N. Mottershead, Weathering of coastal defensive structures in southwest England: a 500 year stone durability trial, *Earth Surf. Process. Landf.* 25 (10) (2000) 1143–1159.
- [40] D.N. Mottershead, Coastal weathering, in: J. Shroder, G.A. Pope (Eds.), *Treatise On Geomorphology. Weathering and Soils Geomorphology*, vol. 4, Academic Press, San Diego, 2013, pp. 228–244.
- [41] D.N. Mottershead, A. Gorbushina, G. Lucas, J. Wright, The influence of marine salts, aspect and microbes in the weathering of sandstone in two historic structures, *Build. Environ.* 38 (9–10) (2003) 1193–1204.
- [42] R. Motti, G. Bonanomi, Vascular plant colonisation of four castles in southern Italy: effects of substrate bioreceptivity, local environment factors and current management, *Int. Biodeterior. Biodegrad.* 133 (2018) 26–33.
- [43] R. Motti, G. Bonanomi, A. Stinca, Biodeteriogens at a southern Italian heritage site: analysis and management of vascular flora on the walls of Villa Rufolo, *Int. Biodeterior. Biodegrad.* 162 (2021) 105252.
- [44] P. Murphy, D. Thackray, E. Wilson, Coastal heritage and climate change in England: assessing threats and priorities, *Conserv. Manag. Archaeol. Sites* 11 (1) (2009) 9–15.
- [45] M. Ottlé, H.D. van Bohemen, A.L. Fraaij, Quantifying the deposition of particulate matter on climber vegetation on living walls, *Ecol. Eng.* 36 (2) (2010) 154–162.
- [46] M. Ottlé, K. Perini, Comparative experimental approach to investigate the thermal behaviour of vertical greened façades of buildings, *Ecol. Eng.* 108 (Part A) (2017) 152–161.

- [47] E. Sesana, A.S. Gagnon, C. Ciantelli, J. Cassar, J.J. Hughes, Climate change impacts on cultural heritage: a literature review, *Wiley Interdiscip. Rev.* 12 (4) (2021) 1–29.
- [48] B.J. Smith, P.A. Warke, J.P. McGreevy, H.L. Kane, Salt-weathering simulations under hot desert conditions: agents of enlightenment or perpetuators of preconceptions? *Geomorphology* 67 (2005) 211–227.
- [49] T. Sternberg, H.A. Viles, A. Cathersides, M. Edwards, Dust particulate absorption by ivy (*Hedera helix* L) on historic walls in urban environments, *Sci. Total Environ.* 409 (1) (2010) 162–168.
- [50] T. Sternberg, H.A. Viles, A. Cathersides, Evaluating the role of ivy (*Hedera helix*) in moderating wall surface microclimates and contributing to the bioprotection of historic buildings, *Build. Environ.* 46 (2) (2011) 293–297.
- [51] F. Thomsit-Ireland, E.A. Essah, P. Hadley, T. Blanuša, The impact of green facades and vegetative cover on the temperature and relative humidity within model buildings, *Build. Environ.* 181 (2020) 107009.
- [52] M.J. Thornbush, Chapter 8: The use of climbing plants in heritage bioconservation, in: B. Veress, J. Szigethy (Eds.), *Horizons in Earth Science Research*, vol 10, Nova Science Publishers, New York, 2013, pp. 231–249.
- [53] P.A. Warke, B.J. Smith, Effects of direct and indirect heating on the validity of rock weathering simulation studies and durability tests, *Geomorphology* 22 (3–4) (1998) 347–357.
- [54] K. Wilhelm, H. Viles, Ó. Burke, Low impact surface hardness testing (Equotip) on porous surfaces—advances in methodology with implications for rock weathering and stone deterioration research, *Earth. Surf. Process. Landf.* 41 (8) (2016) 1027–1038.
- [55] K. Wilhelm, H. Viles, O. Burke, J. Mayaud, Surface hardness as a proxy for weathering behaviour of limestone heritage: a case study on dated headstones on the Isle of Portland, UK, *Environ. Earth. Sci.* 75 (10) (2016) 1–16.
- [56] C. Wood, A. Cathersides, H. Viles, *Soft Capping On Ruined Masonry Walls, Historic England, Swindon, 2018 Research Report Series no. 88-2018. ISSN 2059-4453 (Online).*
- [57] H.A. Viles, Implications of future climate change for stone deterioration, *Geol. Soc.* 205 (1) (2002) 407–418 Special Publications.
- [58] H.A. Viles, T. Sternberg, A. Cathersides, Is ivy good or bad for historic walls? *J. Archit. Conserv.* 17 (2) (2011) 25–41.
- [59] H.A. Viles, A. Goudie, S. Grab, J. Lalley, The use of the Schmidt Hammer and Equotip for rock hardness assessment in geomorphology and heritage science: a comparative analysis, *Earth. Surf. Process. Landf.* 36 (3) (2011) 320–333.