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CULTURAL HERITAGE FACING CLIMATE CHANGE: EXPERIENCES AND IDEAS FOR RESILIENCE AND ADAPTATION

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Policy Relevance of Small Changes in Climate with Large Impacts on Heritage

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Abstract: The climate is changing, but even small changes in temperature or humidity can be amplified by phase changes or biology to suggest that there could be greatly altered threats to material heritage in the future. Our projections for a changed climate lead to estimates of likely future damage and alterations to heritage and the cultural landscapes it occupies. Will the changes in climate simply alter the rate of damage in processes that we already understand, or will qualitatively new damage forms emerge in the future? The output from research can be complex and often difficult to apply to strategies to protect heritage assets, so the emerging body of research needs careful translation into policy.

Résumé: Le climat est changeant, mais même de petits changements en température et humidité peuvent être amplifiés par des changements de phase ou de biologie suggérant qu'ils pourraient modifier les menaces au patrimoine matériel dans le futur. Nos projections pour un changement climatique nous amènent à estimer les probables futurs dommages et altérations du patrimoine et des paysages culturels qu'il occupe. Les changements de climat modifieront-ils simplement le taux des processus de dommage que nous avons déjà compris ou de nouvelles formes de dommages qualitatifs émergeront-elles dans le futur? Les résultats des recherches peuvent être complexes et souvent difficiles à appliquer aux stratégies de protection des objets du patrimoine, aussi les nouveaux corps de recherche nécessitent un transfert prudent en termes de politique.

Key-words: air pollution, cultural landscapes, festival dates, frost shattering, insect attack, salt weathering.

Mots-clés: pollution de l'air, paysages culturels, dates des festivals, éclatement dû au gel, attaque des insectes, dommages dus aux sels.

1. Introduction

The climate is changing. However, the magnitude and direction of such changes can be difficult to establish. The problem for policy makers is that future changes are forecasts and subject to uncertainty. The projections may be subtle spatially and temporally, and more reliable in the case of temperature than with parameters such as wind and precipitation, especially where we are interested in short-term variation. Additionally, the changes tend to be at some distance in the future, so are easily overwhelmed by more immediate day to day concerns.

Climate change is one of the most discussed environmental issues of the 21st century. Few are unaware of its potential, although questions of its magnitude remain. Successive IPCC reports have reinforced the reality of the changes underway and improved estimates of the magnitude of the likely change. Although the IPPC has not specifically recognised the impact that climate change is likely to have on cultural heritage, there is plenty of evidence within the 4th and 5th Assessment Reports that would make the thoughtful reader concerned about the potential impact on heritage. Additionally, there have been a number of European projects, *Noah's Ark* (Sabbioni *et al.*, 2009) and *Climate for Culture* (Leissner *et al.*, 2016) that have funded major initiatives concerned with heritage and climate change. At a national level the UK had projects such as *Engineering Historic Futures* (Cassar and Hawkings, 2007) which took an interest in climate change. Historic Scotland has been anxious to incorporate climate change within the strategy for managing monuments under their care (HS, 2012).

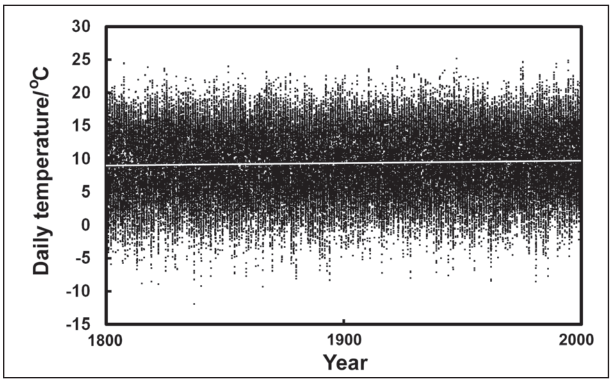
This chapter aims to explore the way in which small changes may have big impacts, with a particular interest in how that affects the way policy is developed with respect to climate change.

2. Amplifying small changes

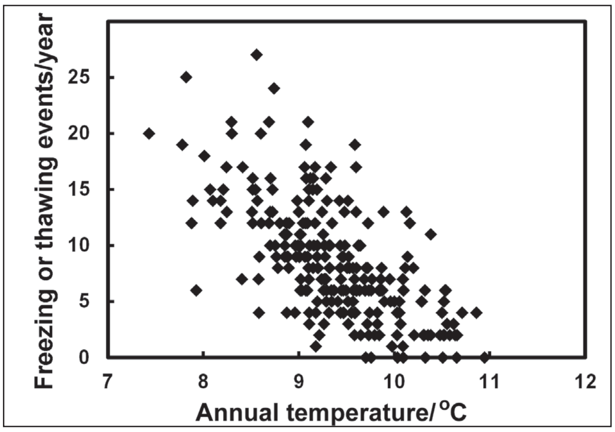
Although it is commonplace to talk about the striking increases in global temperatures, it is easy to forget that these are just a few degrees across the current century. The Intergovernmental Panel on Climate *Change's Climate Change 2013: Synthesis Report* suggest that the increase in global temperature by century's end could be just 1.0°C with stringent emission controls under RCP2.6, although under continued very high greenhouse gas emissions (RCP8.5 scenario) it could be 3.7°C.

Figure 1 shows the daily temperature values (e.g. Parker *et al.*, 1992) from Central England for two centuries from 1801 to 2000. There are more than 73 thousand points, and we can sense a slight increase over time as shown by the white best-fit line. This line has a slope of 0.0039°C per year, just less than four thousandths of a degree, though over two centuries this would amount to about 0.8°C. Such slight changes are dwarfed by the variation in daily temperature, which has a range of around 40°C and a standard deviation of ±5.3°C. Even the projected future increases can seem small in comparison with daily variation in temperature (fig. 1).

Given these seemingly slight changes, why is the changing climate of such concern when a stone on a building façade would hardly seem sensitive to small changes in temperature? Yet, the impact can be magnified in a number of ways. One of the most notable is the way in which climate interacts with porous materials such that phase changes place stress within its structure (Grossi *et al.*, 2007). The freezing of water occurs at a very precise temperature close to 0°C. As water expands during the formation of ice its exerts pressure, so as ice forms in porous stone it can lead to frost shattering. These phase changes can be approximated by assuming they occur when temperature from one day to the next crossed 0°C. Figure 2 shows the number of times freezing or thawing occurred each year in Central England over almost two and a half centuries.

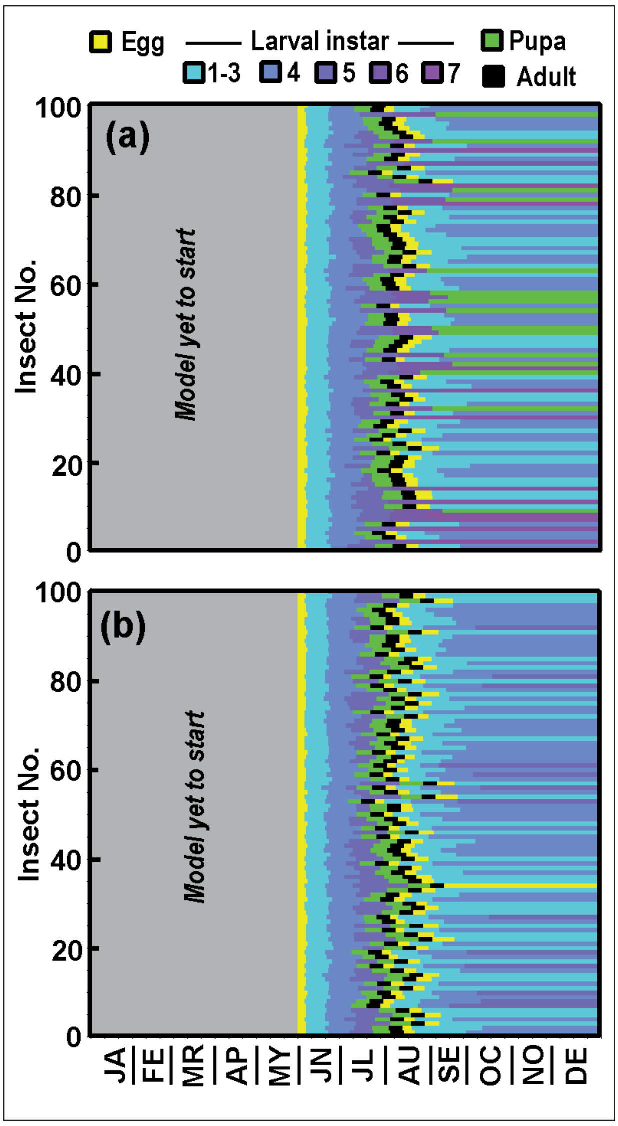


1. - Daily average temperature from the Central England Temperature Record over two centuries. The white line represents a linear best fit.
Température diurne moyenne durant les deux derniers siècles d'après le Central England Temperature Record. La ligne blanche représente le meilleur ajustement linéaire.



2. - The number of freezing or thawing events each year as a function of the annual temperature from the Central England Temperature Record over the period 1772-2016.
Nombre d'évènements de gel-dégel chaque année en fonction de la température annuelle sur la période 1772-2016, d'après le Central England Temperature Record.

The graph suggests that a three degree increase in temperature from 7.5°C to 10.5°C would cause a reduction in the number of events from 25 to almost zero. This provides evidence that quite small amounts of warming could lead to a substantial reduction in frost shattering. It seems likely that in the future this will be a rather unimportant process in the degradation of porous building stones in England. This forecast is useful because it allows heritage managers to focus on other threats that are likely to pose greater risks. Relative humidity changes can induce phase changes in salts within the pores of stone, which exert stresses that cause salt weathering. The transition between a brine and a salt occurs at a precise humidity, so very much as with freezing, small changes in the relative humidity can change the frequency of transitions likely to cause salt weathering. These may increase in frequency in drier climates of temperate Europe,



3. - Modelled insect lifecycles at an annual average temperature of 12°C (a) and 13°C (b).
Cycles de vie des insectes modélisés à une température de 12°C (a) et 13°C (b).

placing stone under greater threat of salt weathering (Grossi *et al*., 2011).

Biological activities that damage heritage materials can also be very sensitive to slight changes in climate. As an example, insect lifecycles are dependent on environmental conditions such as temperature (Brimblecombe and Lankester, 2013). Though it is not easy to establish the impact of climate change in the frequency of insect catches in historic houses (Brimblecombe and Brimblecombe, 2015), sensitivity is readily modelled as found in the case of the yellow-spotted longicorn beetle (*Psacothea hilaris hilaris*).

This beetle is common in Asia where it damages fig and mulberry trees, and has been found in Northern Italy since 2005 (Lupi *et al.*, 2013). The difficulty in controlling the longicorn beetle means that it has been well-studied, and the details of its life cycle are clear enough to allow its life to be predicted in numerical simulations. The model of Watari *et al.* (2002) has been used here to establish the various stages in the life cycle of the beetle. Details are available from their publication, but in essence the model determines the integrated temperatures required to transition from egg, through up to nine larval stages, and then the pupa and the adult. The model used here also allows for adults mating and laying eggs that undergo further development.

The results of the model run with an annual average temperature of 12°C and 13°C are given in fig. 3 where the temperature changes sinusoidally through the year, starting at 14°C below the mean at the New Year and rising to 14°C above the mean mid-year. The model traces the growth of 100 individual eggs that hatch in late May. The one-degree difference in the annual mean temperature makes a profound difference in the lifecycle. Under cooler conditions (fig. 3a) some dozen individuals fail to proceed to the adult form during the summer, and overwinter in diapause or as a pupa. By contrast with a one-degree increase in temperature, all the individuals proceed to adults by July or August, and two thirds over-winter as larva in the 4th instar or beyond.

The sensitivity of biological systems is already evident in the Japanese cultural landscape. The Yayoi Festival heralds spring at the famous temple complex in Nikkō, Japan between 13-17 April, when floats decorated with cherry blossoms parade the streets (fig. 4) and local town leaders s exchange visits in an ancient custom. Any deviation is seen as likely to cause troubles in the coming year. However; as the blooming dates for the cherry trees now arrive so early that floats frequently use artificial flowers. (Brimblecombe and Hayashi, 2017). This is one example of how climate change may affect cultural affairs and landscapes that are relevant to both the heritage and the visitor.

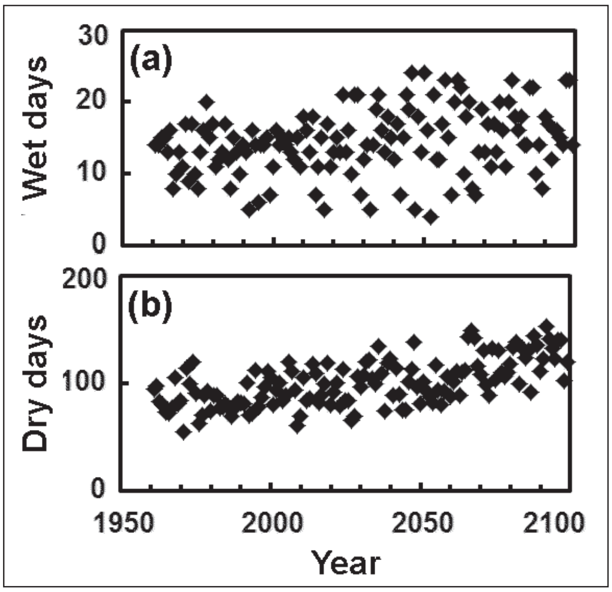
It is difficult to predict future climate, and the problems are greater when we move from

4. - Floats decorated with blossoms during the Yayoi Festival in Nikkō (http://jpninfo.com/39114).
Chars décorés de fleurs durant le Festival de Yayoi à Nikkö (http://jpninfo.com/39114).

temperature (thermodynamic property) to precipitation (dynamic or circulation property). In addition to being more difficult to forecast and highly variable over most spatial scales, the projections are almost contradictory, as seen in fig. 5 which shows the number of wet and dry days predicted for Central England from HadCM3A2 output. It is noticeable here that both the wet and dry days increase across the current century. This seems contradictory, yet it is part of a climate that will see heavier falls of rain, while at the same time the total amount of rain may well decrease.

3. Uncharted territory or continuity

The emerging climate of the 21st century is likely to have more extremes, so it may move well beyond the realms of our past experience. Amplification and extreme events would suggest that we are moving into uncharted territory with respect to impacts on heritage. Despite the magnitude of the likely change, some have argued that this is not really an appropriate way to think about future climate threats, e.g. Roger Lefèvre has said at a number of the conferences held in Ravello, that climate change does not alter the way in which heritage materials are damaged, only the rate at which that damage occurs. This is an important idea, because if true it would mean that we will be responding to threats that we already understand, except that our responses to climate threats to heritage will have to be more rapid (fig. 5).



5. - The annual number of wet days (days >10 mm) and dry days (<0.1 mm) in Central England.
Nombre annuel de jours humides (jours>10mm) et de jours secs (jours <0.1mm) dans le centre de l'Angleterre.

Thus when coping with climate change: if there is really no change in the types of damage, it is an enhanced level of maintenance that is required in future to prevent monuments from being damaged. As what the future will bring is simply more frequent or more intense events. of a character we are already familiar with. Lankester and Brimblecombe (2012) have expressed that idea as something of a corollary where they argue that: "At the moment though, we recognise that future indoor climates often already exist in other locations. This suggests communication throughout the heritage sector will offer examples of the way such challenges have been managed in the past."

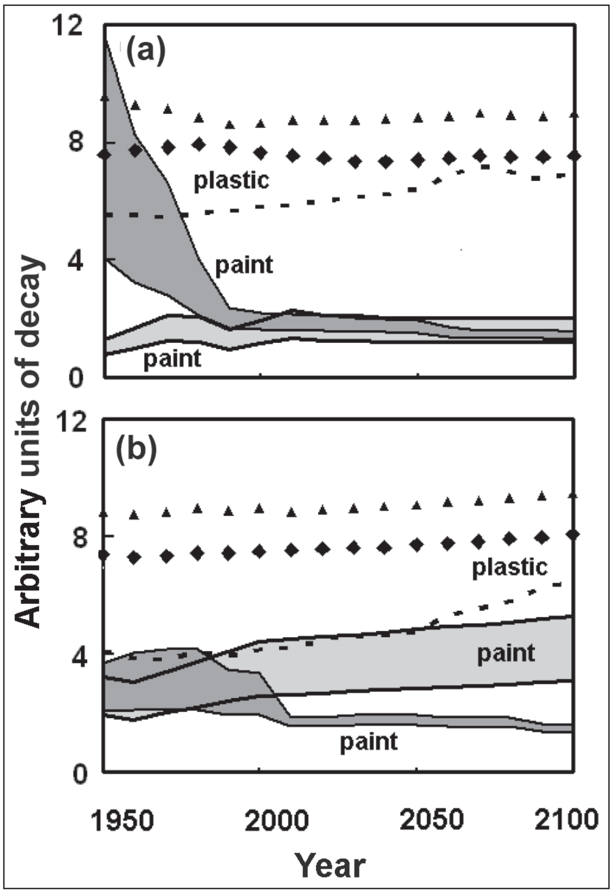
Nevertheless, some of the changes imposed by climate are likely to be so large that they would seem to place us in novel regimes. Climate may be so different by the end of the current century that changes at given places on the earth will be larger than at any time in human history. Although commentators frequently refer to the *Medieval Warm Period*, as a kind of warm optimum; a time when grapes could be grown in England and good wines easily produced. Wines are currently made in the south of England. However, the medieval English vineyards were sheltered by enclosures and at very favourable sites, so it is likely that the previous decade, which has allowed such an increase in wine production, was warmer than anything of the past millennium, including the *Medieval Warm Period*.

As argued earlier, such increases in temperature might not directly take us outside the bounds of experience in conservation. However, some of the indirect effects of climate change might well do this. The projected temperature increase across the current century is unevenly spread, and greater at the poles. Thus, a loss of ice and permafrost exposes Arctic heritage to pressures that seem novel (Murray *et al.*, 2011).

In terms of air pollution, it is initially at least, possible that the future is less uncharted than we might imagine. Regulation and societal pressure has meant that we have concentrations of aggressive acidic air pollutants that are lower in many large cities than for many year,s. In the much criticised book *The Skeptical Environmentalist*, Lomberg argued that sulfur dioxide in London was at its lowest level since the times of Queen Elizabeth. Although we might not agree with the sweeping generalisations at a global level made by the author, the decline in coal burning pollutants at a local level is often as much as two orders of magnitude - a result of a declining use of solid fuels in cities. It has had an impact on the rate of recession of limestone in buildings and metal corrosion on architectural elements. Brimblecombe and Grossi (2009) and Ionescu *et al.* (2012) have modelled rapid decline in the degradation of building materials in London and Paris as the use of coal decreased. This is supported by observations of a less aggressive environment for stone facades of St Paul's Cathedral (Inkpen *et al.*, 2012).

It appears the intense stone recession experienced in these cities likely represents an anomaly to the normal weathering that typified earlier times and the less aggressive atmospheres likely in the future. Brimblecombe and Grossi (2009) suggested that these changes may be interpreted in terms of a Kuznets relationship, well known to economists. It is loosely argued that economic inequality initially increases over time during development, but eventually the variability in income decreases as a society becomes more equitable. Such ideas can be applied to the impact of local pollutants on the population and managing the urban environment. It is proposed that industrialisation initially occurs with little concern over environmental quality, but society eventually reaches a point where environment can no longer be sacrificed.

In the future it is possible that novel pollutants will arise, and these may have an impact that would fail to be anticipated. Recent fears were that enhanced ammonia levels from the intense agriculture of rural Denmark were imposing such



6. - Predicted rate of deterioration of materials in London (a) and Prague (b) in units that are treated in Brimblecombe and Grossi (2010). Plastic is expressed in terms of changes in IR absorption in polyethylene (dotted line), damage depth in polyurethane (diamonds), and colour change in polyester (triangles). Damage to steel panels with alkyd paint (upper and lower bounds of the dark shaded area) and coil coated galvanised steel (light shading).

Taux prévus de détérioration des matériaux à Londres (a) et à Prague (b) en unités traitées dans Brimblecombe & Grossi (2010. Le plastique est exprimé en termes de changements de l'absorption IR dans le polyéthylène (ligne pointillée), de profondeur de dommage dans le polyuréthane (losanges) et de changement de couleur dans le polyester (triangles). Dommages à l'acier peint à l'alkyd (limites supérieure et inférieure de la zone ombrée sombre) et aux bobines en acier galvanisé (ombrage clair).

high loads of ammonium nitrate indoors that murals of the isolated churches were under threat. Although the potential was well argued, thankfully it looks not to be as serious as feared (Skytte *et al.*, 2012). However, the increased sunshine and cloud free days likely for central Europe of the late 21st century have the potential for enhancing ozone concentrations (Brimblecombe and Grossi, 2010). Such elevated ozone levels certainly offer the possibility for increased damage to organic dyes and polymers in the future (fig. 6). Such novel pollutants may well lead us into new and uncharted territories. However, it may be that these represent the continuity imagined by Roger Lefèvre in his comments in Ravello, as potential damage to materials by ozone is well recognised, and it is merely that the rate of attack may increase.

4. Simplification

An increasing amount of research has increased understanding of the impact of climate change on heritage. This can be seen in the publication of literature reviews of the field over the past few years (Horowitz *et al.*, 2016; Fatorić and Seekamp, 2017; Nicu, 2017). Despite the large volume of research, it is not clear how valuable it has been for heritage managers. UNESCO has been very concerned about the risks that climate change poses for heritage for some time about and has published a series of reports on the issue: e.g. *Case Studies on Climate Change and World Heritage,* (Colette, 2007) or more recently *World Heritage and Tourism in a Changing Climate* (Markham *et al.*, 2016). Although these are beautifully illustrated books they tend to avoid extensive detail about research, and focus on colourful presentations, which convince us of the great value of sites under threat. However, it can sometimes be difficult to distinguish damage that is typical of exposure to climate (weathering) and that which arises from climate change.

Heritage management often demands support from research, so neglect of the expanding body of output on the interaction between climate change and heritage can seem surprising. However, the research desired may be more about stewardship and planning, as in the recent report of Melnick *et al.* (2015) which focuses attention on strategy documents rather than more formal academic outputs. This is also seen in literature reviews in the field where much of the analysis pays more attention to policy reports rather than emerging academic research outcomes. This may arise because as argued by Fatoric and Seekamp (2017), the greatest concern of managers relates to institutional barriers to planning and implementation strategies.

There often seems a vast gulf between heritage managers and heritage scientists who are separated by a different methodology and literature. Some admit to a lack of an understanding of climate change (Fatoric and Seekamp, 2017), but there may be other problems in using research. It may be complex, and the output can seem difficult to apply. This may arise because the research work can relate to a specific case study or seemingly inapplicable in practice, as conclusions to research papers can end in vague generalities. Research really requires careful translation into practice. Additionally, as our understanding of future climate is limited it is usually expressed as projections which are subsequently linked to estimates of potential damage. As such these often lack any proper treatment of quantitative and qualitative errors (e.g. Leijonhufvud *et al.*, 2013), and where provided they are difficult to apply to real-world decision making.

Despite these problems, climate research can be used in developing strategies for heritage; an admirable use of climate data from the UKCP09 projections is found in Whittlesea and Amelung's (2010) analysis of tourism in South West England. However, the difficulties of using research often lead to simplifications of the research output. The notion that heritage in England will need protection from a climate that will be warmer-wetter-windier neglects the subtleties of climate change alluded to in fig. 5. It is important to argue for a more refined view of climate change in making decisions about heritage (Brimblecombe, 2014).

5. Concluding thoughts

There is an increasing amount of research of the impact of future climate on heritage. It can make links to historic evidence, in addition to projections into the future. Climate parameters need to be tuned to specific materials or heritage assets. Climate projections, especially for wind or precipitation are far less reliable than those for temperature. There is often concern that the spatial resolution of climate models is insufficient for use in heritage management, but weather generators improve both spatial and temporal resolution. However, it is necessary to move from predictions of potential damage to damage assessments that give an understanding of how errors in climate/damage estimates would affect management decisions. We need to think beyond climate change impacts on monumental heritage and be sensitive to the landscape and the visitor who traverses it.

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