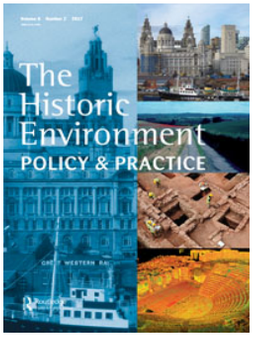

The Historic Environment: Policy & Practice

ISSN: 1756-7505 (Print) 1756-7513 (Online) Journal homepage: https://www.tandfonline.com/loi/yhen20

Predicting and Adapting to Climate Change: Challenges for the Historic Environment

Jen Heathcote, Hannah Fluck & Meredith Wiggins

To cite this article: Jen Heathcote, Hannah Fluck & Meredith Wiggins (2017) Predicting and Adapting to Climate Change: Challenges for the Historic Environment, The Historic Environment: Policy & Practice, 8:2, 89-100, DOI: 10.1080/17567505.2017.1317071

To link to this article: https://doi.org/10.1080/17567505.2017.1317071

THE HISTORIC ENVIRONMENT: POLICY & PRACTICE, 2017
VOL. 8, NO. 2, 89–100
https://doi.org/10.1080/17567505.2017.1317071

Routledge
Taylor & Francis Group

Predicting and Adapting to Climate Change: Challenges for the Historic Environment

Jen Heathcote, Hannah Fluck and Meredith Wiggins

Historic England, The Engine House, Swindon, UK

ABSTRACT
Our changing climate poses risks to the historic environment but also brings opportunities for new discoveries and ways for people to engage with it. At Historic England, part of our responsibility is to understand what future changes we might expect and the impact these may have on our ability to protect historic buildings, archaeological remains and landscapes. This paper describes projects that have used spatial analysis to assess the risk and vulnerability of sites to flooding and coastal erosion. It summarises how we responded to the recent UK Climate Change Risk Assessment and outlines the research we believe is needed to strengthen the evidence base in time for the next cycle of reporting so that the historic environment is better served by the process. Finally, it outlines the adaptive measures that have been proposed to enable Historic England to address the risks and make the most of the opportunities created by climate change.

KEYWORDS
Climate change; historic environment; risk management

Introduction

Historic England (formerly English Heritage) is the public body that champions and protects England's historic environment (historic landscapes, buildings and archaeology). We provide expert advice, promote constructive conservation, carry out research and give grants and guidance to everyone from local communities to national policy-makers. Part of our responsibility is to understand what future changes we might expect, what impact these might have on the historic environment and what risks to its continued protection may lie ahead; that includes considering the impact of climate change.

This paper will focus on how Historic England is factoring predicted climate change into our work. We will summarise recent research, examine current initiatives to develop policy and practice, and use case studies to highlight some of the key issues that have been identified by the historic environment sector.

First though, it is worth reflecting on why we think that climate change is a risk for the historic environment. Current predictions for the UK suggest that both temperature and sea-level are rising.[1] Although there is a significant uncertainty in quantifying the effects of climate

CONTACT Jen Heathcote jen.heathcote@HistoricEngland.org.uk

change, it has been proposed that by 2080, southern England might expect an increase of up to *c.*4 °C in the mean summer temperatures, an increase in mean winter precipitation of up to 33% in the west and a decrease in mean summer rainfall of up to 40%.[2] There is also increasing evidence that rainfall episodes will be more intense and more frequent,[3,4] presenting challenges to rainwater systems in buildings, increasing surface water and risks of flash flooding, erosion and ground stability problems. However, most climate change should be seen as a risk multiplier, accelerating changes that are already happening.[5] We are familiar with the fact that flooding and coastal erosion already occurs and it is the magnitude, frequency and geography of these processes that climate change will affect. Similarly, we are already aware that changing environmental conditions can alter the distribution of animals, plants and pathogens which may have positive, negative or no effect on the historic environment. These changing conditions will affect the historic environment, both directly through the action of attendant physical, biological and chemical processes, and indirectly through the actions undertaken to adapt to or mitigate them. The effects will be felt by all types of heritage asset, whether on land and or in sea, comprising buildings, buried archaeology, parks and gardens and landscapes. The scale of impact will be highly variable, with little or no adaption required for some assets, through to the possible acceptance of unavoidable loss for others.[6] However, change can also expand our knowledge of the past. For example, erosion of the East Anglian coastline has exposed deposits that have revised our understanding of the earliest prehistory of Britain, revealing evidence of early human occupation at Pakefield[7] and Happisburgh.[8]

The potential impacts of climate change on the historic environment are summarised in Table 1, for example inundation, saturation, desiccation and erosion. The nature of impact experienced at a particular place will vary according to the type of site (archaeological remains, standing building or designed landscape) and its landscape context and may not always be problematic. However, for some assets, in some places, mitigating the impact of climate change in the medium to long term might not be viable, practical, or even possible. In such cases, there will need to be a clear strategy for communicating loss of the asset and the reasons for its inevitable decline or loss. Currently, we do not have a clear framework for communicating such ideas although we are beginning to explore them in recent work.[9,10] In addition to these factors, the historic environment will also be affected by actions undertaken by other sectors to adapt to, mitigate for or counter predicted environmental change.

Responding to Climate Change

How can we, as a sector, respond to climate change? There are a variety of approaches that can be taken, from low-risk strategies such as increased emphasis on maintenance, through to higher risk ones that require adaptation of practices or even changes to what we currently find acceptable. Low-risk strategies focus on improving protection from extreme weather events that are already happening and include:

- Prioritising maintenance to ensure buildings are weather proof;
- Increasing the capacity of drainage systems at roof and ground level;
- Increasing the capacity of water harvesting and storage to enhance water security for vulnerable assets.

Actions with a greater risk may require a philosophical shift in the level of adaptation of a place that we might find acceptable, for example:

Table 1. Process, agency and impact.

Process	Agency	Impact
Flooding	Water	Flood water inundation and saturation will damage historic buildings and designed landscapes, particularly if standing water conditions develop. All types of asset may be affected by the erosive power of high energy flood water (e.g. buried archaeology in floodplains) and physical damage from entrained objects (e.g. bridges)
Coastal erosion	Water, wind	Assets on the coastal fringe will become increasingly at risk from inundation, damage or loss from erosion, with foreshore and cliff-top equally vulnerable, depending on geology Dunes, peats and other inter-tidal deposits are likely to come under greater threat if wave energy and storminess increase
Extreme weather	Multiple	Sudden heavy rainfall as well as the cumulative impact from less intense, but repeated, events can be equally damaging Greater extremes and fluctuations of temperature (heat as well as cold) will increase thermal expansion and contraction of materials – wood, stone, metal, paint – causing accelerated attritional damage
Temperature change	Air temperature	Hotter, drier conditions may also increase the risk of fire, particularly for upland landscapes Freeze-thaw erosion of stone that occurs as a consequence of frost action in severe cold weather may diminish if winters become milder, although if temperatures continue to drop below freezing, wetter winters may exacerbate the problem
Water availability	Water	In drier conditions, the risk of soil erosion increases. In dry conditions, soil shrinkage, particularly of those that are clay-rich, can lead to building subsidence, structural deformation and collapse in the most severe cases Desiccation of soils and lowered groundwater levels will also increase the risk of decay to waterlogged archaeological and palaeoenvironmental remains
Species and habitat change	Biological	The distribution and impact of insect and fungal infestations may increase, affecting historic buildings and organic artefacts as well as plants within historic and designed landscapes Changes in temperature and water availability will alter the appearance of some historic and designed landscapes through vegetation change Opportunistic exotic species may thrive, changing landscape characteristics creating new risks for historic buildings and collections

- Changes in land management in upland and lowland areas to enhance flood protection;
- Changes in coastline management to enhance protection from flooding and coastal erosion, but also to abandon defence in some places;
- Changes to historic buildings in areas of high flood risk making them more resilient to inundation and recovery.

In terms of planning for the future, there is an increasing need to assess the vulnerability of particular places and types of heritage asset to different processes so that we understand the scale of problems that might be encountered. There is also a need to prioritise understanding the heritage significance of those places at greatest and/or immediate risk. As resources are finite and the scale of the issue large, a high-level, national overview that identified areas most vulnerable to change would be helpful. This would allow research and resources (e.g. for recording) to be targeted towards those places where change was most likely to be swift and significant, as well as providing a broader geographical context for local observations.

The results of a number of initiatives are already available to us in the coastal zone to help with this endeavour. The Rapid Coastal Zone Assessment Survey (RCZA) is a series of reports that were commissioned by Historic England (then English Heritage) to enhance our

knowledge of the archaeological resource around the coastline of England. These have been used by others, notably the Coastal and Intertidal Zone Archaeological Network (CITiZAN, a Heritage Lottery Fund project) to help identify key zones of concern and provide a framework to mobilise volunteers in the monitoring and recording of sites under threat. The individual RCZA reports are listed on the CITiZAN project website[11] and the publications are available via the Historic England website.[12] The next steps are to create better tools that allow us to refine our understanding of heritage vulnerability to future change in coastal environments, building on those already available, e.g. Futurecoast[13] and Shoreline Management Plans (SMP2).[14] There is also a need to develop comparable resources to understand change in inland contexts. This will require working with partners who deal with measuring and monitoring natural environmental conditions (for example, The British Geological Survey, The Environment Agency and the Met Office), using the data they collect and model in order to refine our understanding of geographically specific change. The next section summarises two pilot studies that used this approach to create risk assessments for the National Collection.

Climate Change and the National Collection: Place-based Assessments

On 1 April 2015, the Historic Buildings and Monuments Commission for England changed its common name from English Heritage to Historic England and separated from English Heritage Trust, which retains responsibility for caring for and presenting the National Collection – a collection of over 400 historic places across England that are owned by the nation. The research discussed in this paper spans that division. Research that was completed prior to the split, dating up to April 2015, relates to looking at the impacts of climate change on the National Collection. Work carried out after April 2015 focuses on the broader historic environment of England.

In order to begin developing our responses to climate change, at English Heritage (and now at Historic England), we have been pursing two research agendas in parallel. One of these looks at impacts on materials (buildings and collections) and the processes that affect them. The other focuses on looking at places by beginning to develop place-based risk assessments that assess the impact of different processes over different timescales.[15,16,17] The approaches taken to create these have varied. The coastal erosion and inland flooding risk assessments used desk-based spatial analysis, overlaying Environment Agency with National Collection data,[18,19] whilst the Stonehenge and Avebury World Heritage Site Risk Assessment[20] was developed through discussing various climate change scenarios and working through the implications of these with stakeholders drawn from many different sectors.

A desk-based risk assessment from coastal change was undertaken for the National Collection over 14 months between 2010 and 2011.[21] The Collection comprises over 400 historic sites and properties in England and of these, 80 are classified as within the coastal zone. The Coastal Erosion Risk Assessment (CERA) assessed the likely impacts of accelerated coastal erosion together with frequent and severe flood events on these properties. Properties were assigned a risk level, based on the likelihood of flooding or coastal erosion and the severity of the potential risk, according to the proportion of the property likely to be affected. To achieve this, digital data were compared in a GIS to identify the extent of

overlap between property boundaries and the predicted flood zones and coastal erosion patterns. Where there was no overlap, the sites were classified at low risk. For those sites, where they did correspond, the percentage area of the site affected was calculated and the risk level (low–medium–high) was allotted. This was further refined by assessing local conditions such as geology, shoreline management policy and condition of the heritage asset.

Of the 80 properties classified as lying within the coastal zone, a number were discounted, including those in urban areas where continued maintenance of flood or erosion defences can be assumed according to national policy at the time the research was undertaken. Although 90% of the properties included in the study were at risk of flooding, only two – Berney Arms Windmill (Norfolk) and Landguard Fort (Suffolk) – were considered at high risk. In terms of coastal erosion, 70% were potentially at risk, with four of those properties – Reculver Roman Fort (Kent), Daw's Castle (Somerset), Garrison Walls and Innisidgen Burial Chambers (Isles of Scilly) – at high risk.

Risks from flooding include not only those relating to destruction by high-energy flood events, but also the damage from repeated, low-energy inundation. Long-term sea level rise over the next 50–100 years was also considered. Of the four sites at high risk from coastal erosion, three (Daw's Castle, Garrison Walls and Innisidgen Burial Chambers) are situated on stretches of coast which lack sea defences, and where none are currently planned. In these cases, it will be essential to ensure adequate recording, monitoring and understanding of the sites prior to their partial, or even complete, loss in the longer term. At Reculver, the site is currently protected by hard coastal defences and the management plan (SMP2) proposes that this is maintained over the next 100 years. However, management of the areas to either side differs, and will result in a changing coastline and hinterland that will alter the landscape setting of the property.

In 2013, a similar desk-based exercise looking at the inland flood risk for the National Collection was published.[22] As with CERA, it included consideration of important infrastructure such as offices, stores, car parks and access routes and used the same broadly comparable approach, identifying 10% of sites at high risk, and a further 6% at medium risk of flooding out of a total of 362 properties. Detailed assessments of the properties at high and medium risk were provided, with mapping to show which parts of the sites were vulnerable, and from what type of flooding. The report also made recommendations for management options intended to inform future discussions between English Heritage Trust, the Environment Agency and Local Authorities.

Potential opportunities exist for further work to refine our understanding of the level and nature of the flood risk, including detailed analysis of what exactly is affected at each of the sites, as well as assessing how closely the flood maps correlate with what happens on the ground. Areas that could fruitfully be explored include: What can local knowledge tell us about flood behaviour at the sites? What does this mean for maintenance programmes? Do these need to be revised or new land management practices introduced to mitigate impact? The Church of England has recently undertaken a comparable exercise, gathering data from local managers to inform site management (Ruth Knight, pers comm.).

UK Climate Change Risk Assessment (CCRA) 2017

Under the Climate Change Act (2008), the UK Government is required to produce a national Climate Change Risk Assessment (CCRA) every five years. The CCRA seeks to identify those areas of risk that need to be prioritised for action under the UK Adaptation Programme (NAP) which also runs over a five-year cycle. The focus is high-level; the original CCRA (2012) reviewed the evidence for over 700 potential impacts of climate change in the UK and analysed over 100 of these across 11 key sectors (none of which include heritage interests) based on their likelihood, the scale of their potential consequences and the urgency with which action may be needed to address them. Given the scale and complexity of the exercise, it is hardly surprising that the picture for the historic environment was not really visible within the report.

The second CCRA[23] provided an opportunity to improve the consideration of the historic environment within the exercise, to deliver evidence where we could and to consolidate our understanding of the research needed – both to get a better handle on risk, but also to strengthen the evidence base for our contribution to the next UK CCRA. However, Historic England has not, to date, typically published peer-reviewed papers in journals to demonstrate the evidence of impact on the historic environment; this is the formal currency upon which the UK CCRA Evidence Report is built. Instead, our focus has been directed towards developing practical and technical advice that can be shared widely through our website and publications, an approach developed in response to our duty to provide expert advice and guidance to everyone from local communities to national policy-makers.

Consequently, our response to the UK CCRA17 came as two parts; the first collated the limited, existing reports which set out evidence and trends that concern us with respect to climate change and the historic environment.[24,25,26] These outline both generic climate change risks and detailed examination of specific threats to a group of assets, namely the National Collection. The second – and most important part for us going forward – outlined what we need to know, identifying the climate change-related risks that are most worrying for the historic environment to 2100, and what information needs to be collected now or in the near future to reduce, better manage or eliminate these risks. This provided us with a research framework, refined through discussion with colleagues from across the sector via a working group on climate change adaptation set up jointly by the Church of England and Historic England (English Heritage as it was then) in 2012, the results of which are presented in Table 2.

Although the framework does not identify who will do the research, the resources required to undertake it or indicate timescales, it is has provided a useful tool to help us, as a sector, begin to identify the most pressing needs, those who are best placed to advance relevant research projects and help to organise ourselves into productive partnerships. It also allowed us to better articulate the risks for the historic environment in future. For many of these, the key requirements will be to:

- Understand what other sectors are doing, particularly with respect to identifying data collected by them that can be reused to address our concerns;
- Share data across our own sector, both here and overseas, to increase the evidence base;
- Work with other sectors to develop multi-disciplinary research projects.

Table 2. Research framework – what do we need to know?

Climate change risks and the historic environment	
Key risks	Primary challenges and responses
Changing rainfall conditions	
Flooding (buildings, archaeology, landscapes)	Map, communicate and mitigate risk Identify and advise on heritage-sensitive solutions
Overtopping of rainwater goods (buildings)	Map and communicate risk Identify where problems already occur Identify affordable and acceptable solutions
Changing groundwater conditions	
Building subsidence (including ruins)	Map susceptible geologies to identify areas of greatest risk Identify which building types are most at risk and define the conditions that lead to failure Identify potential long-term impacts from mitigation actions
Loss of waterlogged-buried archaeology	Map susceptible soils and zones of higher risk Produce site-specific risk assessments for sites of exceptional significance Identify the potential and practicality for maintaining groundwater conditions through deliberate interventions
Plant loss	Map susceptible soils, key species at risk and therefore identifying risk for Registered Parks and Gardens
Changing storm conditions (magnitude and frequency)	
Storm damage to roofs	Map and communicate risk
Coastal change	
Coastal change (erosion patterns and/or rates)	Identify areas susceptible to rapid coastal change and the assets that are vulnerable or will be lost
Sea-level rise	Map and communicate information about landscapes vulnerable to change.
Pests and diseases	
Damage to healthy timber (trees and buildings)	Identify problem species, understand current distribution and map potential risk Identify methods for control
Species-specific plant loss in parks and gardens	Define species that are critical to special character and map sensitivities to particular agents and/or processes Identify potential alternatives for replacing losses
Species-specific timber loss (species critical for repair and maintenance of buildings)	Identify species critically affected as well as new problem diseases and pests Identify alternative timbers and sources
Maladaptation	
Problems arising from poor adaptation of buildings to climate change	Identify problematic adaptation practices; understand and communicate their long-term adverse impact Propose and promote alternative options

The six current priorities published in the UK CCRA are: risks of flooding and coastal change; the impact of high temperatures on health and well-being; risks to natural capital; risks of future water shortages; impacts on the global food system; and risks arising from new and emerging pests and diseases. Some of these very clearly map directly onto the historic environment, others are harder to see, but all will potentially have an impact on heritage assets.

An example of how changes in pests and diseases might affect the historic environment is explored in the text box. The focus on ash dieback stemmed from recognition that the health of tree species is vital to the continued enjoyment and success of historic landscapes and that climate change is already increasing pressure on vulnerable ecosystems.

Case Study: Ash dieback

Ash dieback (Chalara) is a fungal disease caused by Hymenoscyphus fraxineus. The disease causes lesions, crown die back and leaf loss.[27] Both old and young trees are susceptible, though mature trees may be able to live for long periods with the disease. Recently, the genetic markers that accompany resilience in some ash trees have been identified,[28] and this is an important first step in safeguarding the species and repopulating the UK. However, in particular regions of the UK, trees may have specific associations or roles to play in the context of historic buildings or landscapes. This makes the protection of specific trees pressing, and the potential risk multipliers they are exposed to more significant.

The UK Forestry Commission hosts a live outbreak map for ash dieback, which was utilised to gather information about the spread of the disease.[29] In order to begin to identify areas where the presence of ash dieback coincided with secondary pathogenic organisms, maps produced by the National Biodiversity Network were also utilised.[30] The impact of ash dieback is particularly affected by the coincidence of Honey Fungus (Armillaria),[31] which attacks the roots of a number of perennials, increasing their susceptibility to diseases and pathogens. By identifying areas where both Honey Fungus and Ash dieback are co-present, it is possible to forecast the potential spread of the disease into areas where historic landscapes or planting regimes could be at risk. This allows us to begin to think about the viability, affordability or practicality of protecting specific trees, and to present options to the public about what such choices mean.

Coincidence of pests and pathogens are a fairly straightforward example of the kind of spatial analysis undertaken by Historic England to identify future pressure points. However, more complicated are those risk multipliers, e.g. water deficits, which we know will occur, but whose strength and frequency cannot be predicted.

Changes in precipitation are already a consequence of climate change, and cycles of extreme weather are likely to become more prevalent across the UK in the future. Both flooding and drought increase the vulnerability of plant species. However, because we cannot predict the level of precipitation in the future, scenario modelling provides a useful tool for identifying potential future areas at risk. Because our interest lay in changes in the short-to-medium term, we utilised UK climate projection data (showing high, medium and low probability of change in precipitation by the 2020's for a middling emissions scenario. This data pointed to a high likelihood of overlapping risks in the east and south east of the country.

Historic England Climate Change Adaptation Plan

The Climate Change Act 2008 grants Government power to direct organisations to report on the impact of climate change on their organisation, their proposals for adapting to those impacts, and an assessment of progress made since their last report. This is known as the Adaptation Reporting Power (ARP). In response to an invitation from Defra to contribute to the second round of ARP reports, Historic England submitted its Climate Change Adaptation Report to Defra in summer 2016.[32]

The report considers the impacts of the changing climate upon Historic England as an organisation, both in its management of personnel, facilities and equipment and with regard to its role as champion of England's heritage. By looking at how the organisation has been affected by weather-related impacts in the past, how the climate is projected to change in the future, and what impact this will have on Historic England's work, it builds upon earlier work described above to identify key risks and opportunities. It also outlines how Historic England can begin to adapt to the future challenges of a changing climate. Although the report focuses upon Historic England it also has a relevance to the wider heritage sector.

In summary, this report identifies 12 risks relating to heritage advice, five risks relating to organisational operations, as well as eight opportunities for furthering Historic England's key function as champion of England's heritage. To begin to address these risks, and make the most of these opportunities, the report identifies the following adaptive measures for Historic England over the next five years:

- To maintain a 'watching brief' on climate change projections and their associated environmental impacts;
- To support measures to increase workforce resilience;
- To support measures to increase resilience in the historic environment;
- To embed climate change adaptation and environmental risk management within projects and practices;
- To promote the positive role the historic environment can play in informing responses to climate change and associated environmental risks;
- To develop an approach for dealing with inevitable change, including loss;
- To support the English Heritage Trust in addressing climate change impacts.

Climate Change: Risk or Opportunity?

Our changing climate poses a risk to heritage though exacerbating or accelerating natural processes such as erosion and flooding; through increased frequency and intensity of extreme weather events such as heavy rainfall or drought; through rising sea levels; through changes in distributions of flora and fauna, including pests and diseases; and through the way in which people respond to a changing climate. But there are also opportunities which Historic England and the wider sector can use to promote the positive role that heritage can play in preparing for and living with change. There is potential for new discoveries as drought exposes new cropmarks, coastal erosion reveals previously hidden archaeological sites and shifting marine sediments and currents reveal shipwrecks and submerged landscapes. Warmer weather may increase tourism and visits to outdoor sites in particular[33] although this increased opportunity for heritage-related tourism also brings its own challenges in managing the impacts of increased footfall. There are also opportunities where the historic environment can provide a focus for communities experiencing change as, for example, at Kempsey, Worcestershire where the local community raised funds to erect a memorial to the medieval burials discovered during flood defence works.[34]

There is much that can be learnt from the past that can inform integrated solutions to current and future challenges. For instance, many traditional building materials can be more resilient to flood damage than modern replacements and traditionally constructed buildings can also often be much more comfortable in extremely hot weather.[35] We can also learn from how people adapted to change in the past – patterns of settlement and land-use in floodplains, how buildings at risk from flooding were constructed and used, and as our climate changes we can learn from how people outside the UK traditionally adapted to the conditions that we might face.

Some heritage assets can themselves make contributions to adapting to climate change: urban green spaces, many of which are heritage assets, make a considerable contribution to alleviating the urban heat island and, if looked after, can also help reduce risks of surface water flooding as well as improving air quality; well-maintained water-meadows can help alleviate river flow.

Climate change, and society's need to respond and adapt to it, are encouraging all organisations to think differently and seek novel solutions. There is a real opportunity for the heritage sector to play a positive role in communicating and adapting to the changes, often through collaboration in areas we might not traditionally view as our domain. The historic

environment sector is used to taking a long view. Not just in our understanding of the past but also in the way we seek to conserve it for the future. This means we are extremely well equipped to contribute to planning for future changes.

Notes

1. Intergovernmental Panel on Climate Change (IPPC), *Synthesis Report*.
2. Jenkins et al. *UK Climate Projections*.
3. See note 1 above.
4. Kendon et al., *State of the UK Climate 2015*.
5. Croft, *Assessment of Heritage at Risk*.
6. Historic England, *Facing the Future*.
7. Parfitt et al., "The Earliest Record of Human."
8. Parfitt et al., "Early Pleistocene human occupation."
9. See note 6 above.
10. Fluck, *Climate Change Adaptation Report*.
11. www.citizan.org.uk/resources/rczas/ [accessed 5 February 2017].
12. www.HistoricEngland.org.uk [accessed 5 February 2017].
13. http://www.coastalwiki.org/wiki/FUTURECOAST project, UK [accessed on 5 February 2017].
14. https://www.gov.uk/government/publications/shoreline-management-plans-smps/shoreline-management-plans-smps [accessed on 5 February 2017].
15. Hunt, *English Heritage*.
16. Pearson, *Flooding and the English Heritage*.
17. Thomas, *Stonehenge and Avebury WHS*.
18. See note 15 above.
19. See note 16 above.
20. See note 17 above.
21. See note 15 above.
22. See note 16 above.
23. ASC, UK, *Climate Change Risk*.
24. Gates, *Gardening in the Global Greenhouse*.
25. See note 5 above.
26. See note 17 above.
27. Forestry Commission, *Ash dieback disease*.
28. Harper et al., "Molecular Markers for Tolerance."
29. http://chalaramap.fera.defra.gov.uk/
30. http://nbn.org.uk/
31. https://data.nbn.org.uk/Taxa/NHMSYS0001474863
32. See note 10 above.
33. Markham et al., *World Heritage and Tourism*.
34. Hancox et al., *Flood Risk Management*.
35. Kovats and Osborn, *UK Climate Change Risk*.

Acknowledgements

The authors would like to thank Dr Robyn Pender, Historic England.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Notes on Contributors

Jen Heathcote is the head of the Strategic Research and Partnerships Team at Historic England. Her career began as a geoarchaeologist and then moved into strategic research, first dealing with wetlands and then broader environmental issues. She took up her current role in 2017, leading a team who assess threats and identify opportunities to benefit the historic environment.

Hannah Fluck FSA is the head of Environmental Research in Historic England's Strategic Research and Partnerships Team. She has an academic interest in Pleistocene archaeology and over a decade's experience as a local government archaeologist in Hampshire and Oxfordshire. Hannah joined Historic England in 2015, and works on flooding, coastal change and ecosystem services; she is the author of Historic England's report on climate change adaptation.

Meredith Wiggins is an environmental analyst in Historic England's Strategic Research and Partnerships Team. She has a passion for creating novel methodologies to utilise undervalued or incomplete datasets, and enjoys working at the intersection of the natural and built environment.

Bibliography

ASC. *UK Climate Change Risk Assessment 2017 Synthesis Report: Priorities for the Next Five Years*. London: Adaptation Sub-Committee of the Committee on Climate Change, 2016. Accessed February 5, 2017. https://www.theccc.org.uk/UK-climate-change-risk-assessment-2017/

Croft, A. *Assessment of Heritage at Risk from Environmental Threat. Key Messages Report for English Heritage*. Birmingham: Atkins Heritage, 2013.

Fluck, H. *Climate Change Adaptation Report*. Research Report Series 28/2016. Swindon: Historic England, 2016. Accessed October 31. http://research.historicengland.org.uk/Report.aspx?i=15500

Forestry Commission (Pest Alert). *Ash Dieback Disease*. Forestry Commission, March 2013. Accessed October 31, 2016. http://www.forestry.gov.uk/pdf/FCPH-ADD.pdf/$FILE/FCPH-ADD.pdf

Gates, P. *Gardening in the Global Greenhouse: The Impact of Climate Change on Gardens in the UK*. Summary Report. Oxford: UK Climate Impacts Programme, 2002. Accessed October 31, 2016. http://www.ukcip.org.uk/wp-content/PDFs/Gardens_summary.pdf

Hancox, E., J. Hanson, A. J. Howard, and R. Jackson. *Flood Risk Management and the Historic Environment: An Analysis of Historic Environmental Practices in Respect of Planning for, and Responding to Flooding*. Worcester: Worcestershire County Council and Landscape Research & Management, 2015. Accessed February 2017. http://www.worcestershire.gov.uk/downloads/file/7281/final_report_and_case_studies_spring_2015

Historic England. *Facing the Future*. Swindon: Historic England, 2015. Accessed October 31, 2016. https://content.historicengland.org.uk/images-books/publications/facing-the-future/facing-the-future.pdf/

Harper, A. L., L. Vig McKinney, L. Rostgaard Nielsen, L. Havlickova, Y. Li, M. Trick, et al. "Molecular markers for tolerance of European ash (*Fraxinus excelsior*) to dieback disease identified using Associative Transcriptomics." *Scientific Reports* 6 (2016). Accessed October 31, 2016. http://www.nature.com/articles/srep19335

Hunt, A. *English Heritage Coastal Estate Risk Assessment*. Research Report Series 68/2011. Swindon: English Heritage, 2011.

Intergovernmental Panel on Climate Change (IPPC). *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC, 2014. Accessed October 31, 2016. https://www.ipcc.ch/report/ar5/syr/

Jenkins, G., J. Murphy, D. Sexton, J. Lowe, P. Jones, and C. Kilsby. *UK Climate Projections: Briefing Report*. Version 2. Exeter: Met Office Hadley Centre, 2010. Accessed October 31, 2016. http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87867

Kendon, M., M. McCarthy, S. Jevrejeva, and T. Legg. *State of the UK Climate 2015*. Exeter: Met Office, 2016. Accessed October 31. http://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/r/4/state_of_the_uk_climate_2015.pdf

Kovats, R. S., and D. Osborn. *UK Climate Change Risk Assessment Evidence Report: Chapter 5, People and the Built Environment*. Contributing authors: K. Humphrey, D. Thompson, D. Johns, J. Ayres, P. Bates, M. Baylis, S. Bell, A. Church, S. Curtis, M. Davies, M. Depledge, D. Houston, S. Vardoulakis, N. Reynard, J. Watson, A. Mavrogianni, C. Shrubsole, J. Taylor and G. Whitman. London: Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, 2016. Accessed February 5, 2017. https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Chapter-5-People-and-the-built-environment.pdf

Markham, A., E. Osipova, K. Lafrenz Samuels, and A. Caldas. *World Heritage and Tourism in a Changing Climate*. Nairobi and Paris: United Nations Environment Programme and United Nations Educational, Scientific and Cultural Organization, 2016. Accessed February 5, 2017. http://whc.unesco.org/en/activities/883/

Parfitt, S. A., R. W. Barendregt, M. Breda, I. Candy, M. J. Collins, G. R. Coope, P. Durbidge, et al. "The Earliest Record of Human Activity in Northern Europe." *Nature* 438 (2005): 1008–1012. doi: 10.1038/nature04227. Accessed December 30, 2016. http://www.nature.com/nature/journal/v438/n7070/abs/nature04227.html

Parfitt, S. A., N. M. Ashton, S. G. Lewis, R. L. Abel, G. R. Coope, M. H. Field, R. Gale, et al. "Early Pleistocene Human Occupation at the Edge of the Boreal Zone in Northwest Europe." *Nature* 466 (2010): 229–233. doi: 10.1038/nature09117. Accessed December 30, 2016. http://www.nature.com/nature/journal/v466/n7303/abs/nature09117.html

Pearson, T. *Flooding and the English Heritage Inland Estate*. Research Report Series 51/2013. Swindon: English Heritage, 2013.

Thomas, B. *Stonehenge and Avebury WHS Climate Change Risk Assessment 2014*. UNESCO, 2014. Accessed October 31, 2016. http://www.stonehengeandaveburywhs.org/assets/Climate-Change-RA-for-web.pdf