The role of science in the management of the UK's heritage

National Heritage Science Strategy

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Cover image
Anne-Marie Miller carrying out paper repairs to holes resulting from iron gall ink corrosion on a page from Aristotle's Historia Animalium (1595) [Add Ms 82955]. *Photo: Barry Knight; British Library Board.*

Executive summary

This report is the first of three which provide the 'evidence-base' for a UK wide strategy for heritage science, covering both movable and immovable heritage. The formulation of a strategy is one of the recommendations to come from the House of Lords Science and Technology Committee inquiry into science and heritage held in 2006.

The report summarises the range of heritage assets present in the UK in museums, galleries, libraries, archives, the built historic environment and archaeological sites. It reviews the principal deterioration mechanisms that affect these assets, and the ways that these threats can be reduced and managed. Through wide-ranging consultation and drawing on past and existing strategies, gaps in knowledge are identified which, if addressed, would improve the current and future management of the UK's heritage. These are categorised into three themes within the report *understanding material behaviour, understanding environments* and *improving practice*.

The first theme (understanding material behaviour) describes the need for further research to improve our understanding of the rates at which heritage materials are affected by a range of deterioration agents and the thresholds at which damage takes place. Although these issues are relevant for all heritage assets covered in this report, a specific focus is given to modern materials in this theme (reflecting the limited research that has taken place to date and the inherent instability of many modern materials).

The second theme (understanding environments) focuses on the additional information that is required to improve the management of environments for display, storage and long-term survival of heritage materials. It highlights current moves to identify low energy, low 'tech' methods of environmental management in response to increasing energy and climate change. The effects of climate change on heritage management is also covered in this theme. Areas for further research to aid adaptation are identified along with issues such as improved understanding of the thermal performance of historic buildings, which will increase future energy efficiency and sustainable use.

The final theme (improving practice) contains recommendations to increase the range of assessment and monitoring techniques, with an emphasis on the development of non-destructive techniques that are cheap, easy to use and portable. This theme also makes suggestions about how to extend our understanding and treatment of past conservation interventions; how to ensure current techniques remain effective and appropriate; and also identifies areas for development of new techniques. Finally, although new techniques are needed to augment the current range of assessment and investigation tools, this report highlights a need for greater availability of information about, and access to existing techniques and facilities.

The report does not identify how best to ensure that the gaps in knowledge outlined above are addressed. That is the purpose of the strategy, which will be drawn up utilising the information presented here and in the next two reports published as part of this process.

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1.0 Introduction

This report describes the role that science plays in the management of the nation's heritage. It considers how this heritage can be sustained so that it continues to enhance knowledge and provide enjoyment for ourselves and future generations. A significant challenge to long-term management is that all heritage assets are liable to decay. A scientific understanding of how these decay processes work is needed. Without this, there is a risk that this rich resource of cultural information will be lost. The processes of deterioration are complex, involving interactions between objects, the environment and people. In many cases, the nature of these interactions is not clearly understood. This report identifies areas where a lack of scientific and technological knowledge jeopardizes the survival of cultural assets and thus the intangible qualities that they evoke for the people who use and enjoy them.

What is heritage science?

The term heritage science is used in this report (and throughout the development of the strategy) to encompass all technological and scientific work that can benefit the heritage sector, whether through improved management decisions, enhanced understanding of significance and cultural value or increased public engagement.

1.1 Background

In 2006, the House of Lords Science and Technology Committee held an inquiry into science and heritage. Their report concludes that the previous high regard in which the UK heritage science sector had once been held is now under threat: the sector is fragmented and under-valued; conservation and sustainability of cultural heritage is not given enough importance in Government policy; there is insufficient transfer of new scientific research to heritage practitioners, and there is no strategic overview of research priorities for heritage science.

One of the main recommendations of their report is the need for an all-embracing UK-wide strategy for heritage science. This current report provides the first part of the evidence base drawn up to aid the development of that strategy. Its aim is to assess the role of science in managing the UK's heritage. Two further evidence-base reports will be produced. The first considers the use of science in understanding the UK's heritage. The second looks at sector capacity and knowledge transfer, both now and in the future. This report has been compiled by the Strategy Coordinator, drawing on previous strategies and studies throughout the heritage and heritage science sector. The Strategy Steering Group (see appendix 1) has provided input and assistance. Interviews and questionnaire responses have been sought from heritage scientists across the UK.

1.2 Structure of report

This report is divided into three parts.

- The heritage sector
- Material decay
- Gaps in knowledge and practice

The first two sections are included to ensure that all readers have a good overview of the range of heritage assets covered by the strategy and the principal threats which affect their long-term survival.

The first section of the report defines and describes the various heritage sub-sectors within the UK and considers the range of materials that comprise each of these and the differences in the management of these resources. The second section summarises the principal agents of decay of heritage materials, the techniques used to monitor decay and ways of managing and reducing its affects. The final section of the report draws together the gaps in existing knowledge and practice, and identifies opportunities for tackling these issues.

This report is a summary of current knowledge, drawn together to assist the steering group draw up the final strategy. It is not a detailed academic literature review; the sources used have been those readily available during the time that this report was produced. These are general publications, existing strategies and information provided by practitioners. These are listed in the references section at the end of the report.

2.0 The heritage sector

There is no one heritage sector in the UK. The individual parts are wide and diverse, primarily divided into rather independent sub-sectors, often based around national location and type of material. The sub-sectors that are used in this report are: museums and galleries; libraries and archives; the built historic environment; and archaeology. In England, responsibility for culture resides with the Department for Culture, Media and Sport, but it is a devolved responsibility in Scotland, Wales and Northern Ireland (see appendix 2 for further information). Within this report, the terms movable and immovable are also used, to distinguish between predominantly indoor, collections-based material (libraries, archives, museums and galleries), and outdoor, buried or built heritage (see Figure 1).

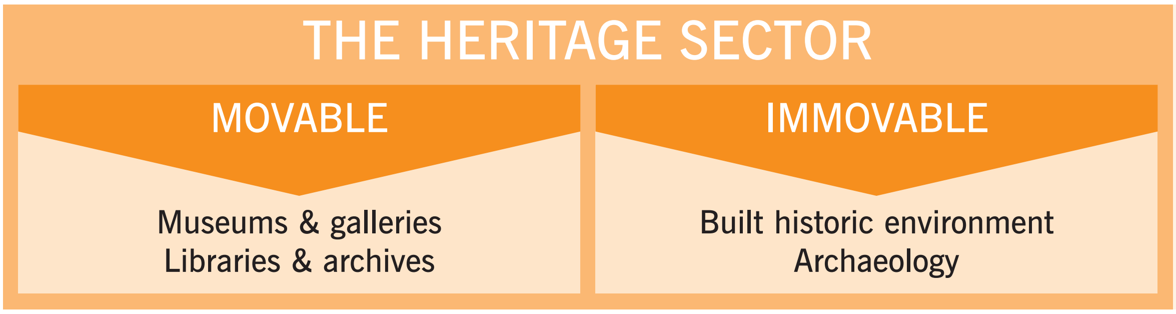

Figure 1
The heritage sub-sectors in the UK.

Any division of heritage is artificial and there are many instances where one sub-sector crosses over with another. Nevertheless, these sub-sectors are usually the level at which people working in these individual disciplines interact with each other, through their literature, conferences, working groups and professional bodies. For this report, these sub-sectors and their significance and value to society are briefly described below. A summary of the types of materials encountered and the contexts in which these different heritage assets are found is also given. This highlights the complexity of the objects, buildings and sites discussed in this report and the strategy in general.

Conservation/preservation?

The terms 'conservation' and 'preservation' are both used in this report. Conservation is the term commonly used within the museums, galleries and historic building sectors. Preservation is used in the libraries, archives and archaeological sectors. 'Conservation' is usually split into two parts, 'interventive conservation' or 'remedial conservation' (which describes treatment) and 'preventive conservation' (which describes the management of inevitable change, in order to ensure the long-term survival of heritage assets). The term 'conservation' is also used in libraries, archives and by archaeologists to describe treatment, while 'preservation' is used to describe long-term management, in the same way as 'preventive conservation'. These terms are used in this report where they relate to these specific sectors.

2.1 Museums and galleries

UK museums and galleries contain a wide range of materials from across the world, reflecting the scope and collecting practices of museums over the last three centuries. These collections, and their display in public galleries, allow visitors to understand the technological, social and artistic development of human societies, and to learn about variety and change in the natural world. They are a valuable resource for detailed research, in a variety of disciplines, such as art history, or in the taxonomy of species. In addition, many museums are repositories for archaeological archives, the permanent record of excavations, and often an essential source for further archaeological analysis.

There are around 2500 museums and galleries in the UK with national museums and galleries in each of the four UK home countries and many other institutions of different scales, operated by local authorities, universities, independent charities and other organisations. Many historic houses (e.g. National Trust, Historic Houses Association) are also registered or accredited museums. UK museums attract 80 million visits every year, and research carried out for DCMS suggests that around 40% of people living in England visit at least one museum a year.

2.1.1 Museums and galleries – types of material

The range of materials encountered within the UK's museums and galleries covers most materials ever manufactured or used. Their dates can span from hundreds of thousands of years ago to the very recent past and in size from the smallest bead, or fragment of preserved clothing to large working steam engines and everything else in between. Common materials include:

- Inorganic – vitreous materials (ceramics and glass), stone, metal
- Organic – wood, paper, textiles, leather, biological (i.e. natural history) collections, plastics

Museum and gallery collections include archaeological, historical, ethnographic and contemporary domestic and industrial artefacts, decorative and fine art works on paper, canvas or wood, as well as textiles, sculptures and ceramics, and an ever increasing range of modern, digital, media. Many items are composites of a number of different materials. An upholstered chair may comprise wood, hair or other padding, webbing, a leather or textile cover, metal tacks and perhaps feet, and maybe even plastic wheels. Oil paintings are composed of a wooden stretcher, canvas, pigment, binder and varnish.

Over time, the range of materials employed for decorative and fine arts, and in the production of everyday objects used in the past has become ever more varied. This includes the development of different pigments and binding agents from the middle of the nineteenth century onwards and synthetic materials during the 20th century, including photography, film and sound recordings. Ethnographic collections can contain organic materials which are not necessarily familiar objects in the UK, as in Figure 2. The content of archaeological archives is predominantly artefacts (most of which have been recorded but not necessarily conserved), as well as the documentary archive of the excavation, comprising site-based records, e.g. context sheets (paper or digital), site drawings (permatrace drafting film or CAD) and photographs (print, slide or digital).

Figure 2
Surface cleaning ethnographic materials. This Balafon, from Sierra Leone and acquired in 1884 is made from a variety of different woods, has gourds which add resonance, and is held together with a range of fibres and natural glues. Image shows treatment being undertaken by Charles Stable at the National Museums Collection Centre, Edinburgh.
Photo: Jim Williams.

Figure 3
Nova stacking milk jugs (Styrene-acrylonitrile copolymer). Designed by David Harman Powell, made by Ecko Plastic Ltd 1967. © V&A Images/Victoria and Albert Museum, London.

Figure 4
Red Drawing Room at Uppark House, West Sussex. Most objects are on open display unlike museums where most material is in cases.

2.1.2 Museums and galleries – context of material

The display context of collections varies depending on the venue, fragility and significance of the material on display. A careful balance has to be struck between providing public engagement with the collections, and maintaining the collections for the future. Climate controlled rooms and display cases can buffer materials from potentially damaging deterioration agents, such as changes in temperature or humidity and can reduce the impact of dust pollution. In many major collections watercolours, and most oil paintings too, are glazed and backboarded, providing similar protection to display cases used for museum objects. Light sensitive materials within museums and galleries are usually displayed in reduced light conditions. Within historic house museums or living and open air museums such as St Fagans National History Museum (National Museums of Wales), the entire contents (pictures, furniture, wall coverings, carpets, porcelain, books etc) are on open display (see Figure 4). In these situations it is harder to control the affects of relative humidity, light, temperature, and pollutants for example.

Although museums and galleries engage the public through display of the most significant items in their collections, a much greater proportion of the collection is in storage, perhaps offsite. Many of these stores are accessible for specialist study; some are reserve or reference collections, maintained for the purpose of research. Across the UK's museums and galleries, storage conditions vary from secure, climate-controlled purpose-built facilities to those lacking appropriate housing or adequate controls. Larger (often agricultural, engineering or industrial) items are often stored and displayed outside either because of their size or a lack of suitable storage, which afford them less protection from the environment.

2.2 Libraries and archives

As with museums and galleries, library and archive material is used to carry out research and enhance our knowledge of history and society but mainly through records of society rather than its cultural products. Books can have a physical, artefactual value as well as a documentary value; the 'archaeology' of the composite materials of a book or codex. The types of records held in archives includes government documents (local and national), census returns, hospital records, records of births, deaths and marriages, migration records (passenger lists), maps, land titles and court records. Many of these records are used by those interest in exploring their own local history and genealogy. Company archives can shed light not just on the history of the company, but its role in the world, and perhaps tell us something about the countries where it operated.

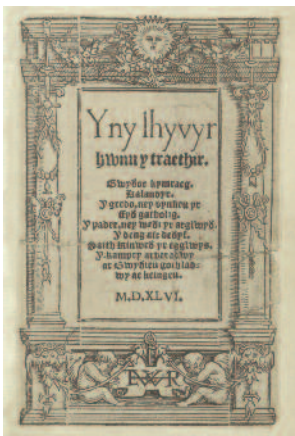

Figure 5
Yny lhyvyr hwnn (1546)
The first printed Welsh book.
By permission of Llyfrgell Genedlaethol Cymru / National Library of Wales

In the UK there are over 4000 public libraries and around 2000 archives, many containing collections of significant value to the nation's cultural heritage. There are five legal deposit libraries in the UK (Bodleian Library, Oxford; The British Library; Cambridge University Library; National Library of Scotland; National Library of Wales), which have the right to receive copies of every book published in the UK. In addition, there are local authority libraries, higher and further education and school libraries, as well as significant collections of books in cathedral, church, historic house and private libraries. Archive collections have similar distributions and are maintained by national archive institutions in England, Wales, Scotland and Northern Ireland, local authority archive services (local record offices), universities, many local and learned societies, and a large number of companies.

2.2.1 Libraries and archives – types of material

The collections in libraries and archives have been predominantly written and printed works on paper. They include books, maps, newspapers, documents and letters. Older documents may be written on parchment or vellum, and other materials used to write on, such papyrus, palm leaves, or birch bark are also present in specialist collections. Within in the last hundred years the advent of other papers, such as architectural drawing film has widened the range of materials entering library and archive collections. Although the majority of the collections are therefore cellulose-based, the quality of the paper can vary considerably; some 19th century papers are acidic because of the raw materials used in their production. As with objects in museums and galleries, historic books are a composite of materials, paper, ink, leather, board, stitching and glues; increasingly other materials are used in construction, for example plastics.

Documents, reference books and manuscripts preserved in archives and libraries may be unique or one of only a small number of surviving copies. For that reason, appropriate storage is essential, and many original records and documents have been transferred to other media, such as microfilm, or through digitisation. These developments also provide greater public access through applications such as the 'digital mirror' of the National Library of Wales and the 1911 online Census at The National Archives. Increasingly, digital developments are having a massive impact on the nature of libraries and archives; the amount and diversity of digital data now being generated which require preservation and access is vast. A new discipline of digital preservation has emerged, which bridges IT, data management and physical preservation of digital information carriers (e.g. CDs). This is still in the early stages of development, and can be expected to throw up new materials science and preservation challenges.

Exploring the range of the British Library collection

The British Library has 12 million books in its collection, on 642 linear kilometres of shelves, which includes many nationally and internationally significant early books and documents, such as a copy of the Magna Carta, the Lindisfarne Gospels, the Codex Sinaiticus (the earliest New Testament) the Gutenberg Bible, and Shakespeare's First Folio. Although books and manuscripts are clearly the core of their collection, the BL also contains a surprising range of other items, including maps, patents, magazines and newspapers. There is also a substantial range of digital material of over 300 terabytes, ranging from web sites to 3 million sound recordings within the sound archive, as well as the associated hardware to play recordings on. The library also contains non-paper based materials associated with the mainstream collections: wax and lead seals; copper printing plates for maps, plaster relief maps, globes, map jigsaws; free gifts associated with magazines (e.g. teddy bears); printing plates for stamps, printing press for stamps; India Office archive: easel paintings, furniture, costume, weapons and photographs.

2.2.2 Libraries and archives – context of material

While some archive and library collections are located within specific climate controlled stores rather than on shelves and immediately available to visitors, others are stored in conditions where the environment is not adequately monitored and controlled. Whilst surrogacy can in certain cases reduce handling of originals, nevertheless, a significant characteristic of library and archive collections is that the physical items is used; material can be subject to considerable wear and tear from usage and transport from the stores to the reading rooms. Additionally, the storage environment and that of the reading room may differ, with one controlled for the management of the collection, the other for the comfort of staff and visitors.

2.3 The built historic environment

The conservation of the built historic environment is important because these structures provide people with a sense of place. Local historic buildings are a key part of an area's character, and differences in vernacular building materials and styles contribute to regional and local distinctiveness. Many historic buildings have an strong amenity value, in terms of the social use to which they are put, ranging from civic and commercial activities to private dwellings; others are maintained and opened to the public as locally, nationally and/or internationally significant works of art and architecture in their own right. They can provide an insight into social history, and may be places of importance as the locations of important historic events.

Historic buildings form a considerable part of the country's built environment. Around 25% of all buildings in the UK were constructed before the 1920s, which equates to approximately 5 million buildings. Of these, over 400,000 are designated as listed buildings, and numerous unlisted historic buildings are protected within approximately 10,000 conservation areas across the UK. As well as traditional material such as timber, brick, stone and metal (see figures 6 & 7), this report also considers 20th century construction materials such as modern concrete and polymers, as these comprise a significant element of the UK's post-war heritage (see figure 8).

Maintenance of historic buildings is the responsibility of the owner, whether a private individual, company, charity or the state. There is a duty for owners of listed buildings to ensure that they are properly cared for. Where such buildings fall into neglect, owners can be encouraged by local authorities to carry out repairs, and in some cases grants are available. Re-development of historic buildings (in particular listed buildings) is regulated by local authorities, with advice from statutory heritage agencies for highly listed or graded buildings. In total, over 40% of construction work is repair and maintenance rather than new build; and half of that is work on historic buildings. It has been estimated that the buildings conservation sector is worth more than £3.5 billion annually.

Figure 6
Tombland Alley, Norwich, including the mid-16th century house of Augustine Steward. Photo: Seán O'Reilly

Figure 7
Georgian terrace houses, Great King Street, Edinburgh, North side, designed by Robert Reid, 1804.
Photo: Seán O'Reilly

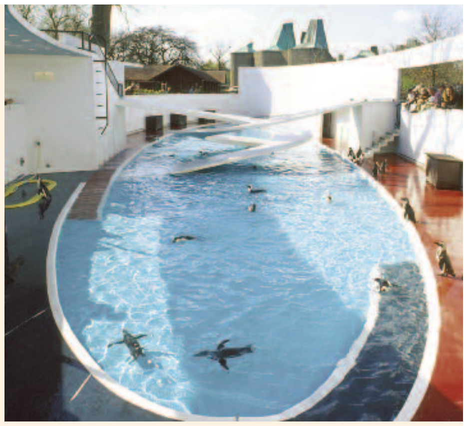

Figure 8
Penguin Pool, London Zoo, designed by Lubetkin and Tecton (1934), with Sir Hugh Casson, Neville Conder and Partners' Elephant and Rhinoceros Pavillion (1965) in the background. © Mr. Dan Woodrow. Image supplied courtesy of Images of England.

Although buildings (residential, commercial and industrial) are a major component of the UK's built historic environment, there are many other significant structures (bridges, canals, architectural ruins, walls and other boundary features) and objects (grave markers, milestones, sculptures) which are key features of our cultural landscape.

2.3.1 The built historic environment – types of material

Figure 9
Standing archaeological remains (architectural ruins) such as these at Hailes Abbeys, Gloucestershire are covered within sections on the historic built environment due to similarities in response to environmental pressures. Photo: H. Viles

The use of any particular construction material (i.e. the type of stone, or tile or thatch) is partly dependent on the local availability of raw materials, i.e. geology, but is also affected by changing styles and fashions. As a result, there is great variety (and complexity) in the design of buildings and other structures across the UK. The majority though are constructed from stone or brick with mortar, as well as wood, and from the 19th century, metal or concrete. Roofing is typically slate, tile, shingle or thatch. Of these building materials, the organic materials (i.e. wood and thatch) and the metals are the most susceptible to natural degradation, although some building stones or materials such as cob, are more fragile than others, particularly if they are poorly designed and/or maintained. Weathering of sandstones, for example, can cause loss of surface detail, and structural instability. In a sample of stone buildings from Glasgow, of the 241 stone buildings surveyed, 97% had facades in need of repair to some extent, while 30% of facades required urgent maintenance to prevent further stone decay.

The interiors of historic buildings, including the non-movable fixtures and fittings such as doors, stairs, plasterworks walls and ceilings, with decorative finishes of paint, wall paintings, or wallpaper are also of significance in demonstrating how houses were used in the past, and the aesthetic sense of those who designed these interiors. Historic house museums often contain contemporary furnishings and decoration, representing the changing styles and fashions of the past few hundred years.

2.3.2 The built historic environment – context of material

The vast majority of historic buildings are in private ownership, constantly lived or worked in, adapted to meet the needs of their owners. Other structures, such as bridges or architectural ironwork (railings, street furniture etc) are important parts of the public realm. The conservation of these buildings and structures must therefore be compatible with, and is in fact often enhanced by their continued use; buildings that are not used are more likely to sustain damage from neglect and vandalism, including fire. However, it is important that any conservation work that takes place is carried out using appropriate materials. Much damage to traditional buildings has been caused by inserting incompatible materials into them as a quick or cheap fix. For example, the use of cement rather than lime mortar can lead to the rapid erosion of porous stones.

2.4 Archaeology

Archaeological research, and the dissemination of the results of that work in museums, through site display or publication brings the past to life. Archaeological sites and materials offer a unique link to the lives of people live many millennia ago, and analysis of excavated material provides evidence of how people interacted with their environment, what they ate, where they lived and how they died. The majority of archaeological research and practice in the UK is directed towards investigating the context and significance of archaeological artefacts, sites and landscapes and therefore, will be covered in report two. The archaeology section of this report covers only the preservation of archaeological remains, below ground and offshore.

There are over a million known archaeological sites in the UK, the vast majority of which are in private ownership. Very few sites are in public ownership (as protected sites and/or visitor attractions), and only 2–3% are protected by being designated as sites of national significance (i.e. scheduled monuments). Known sites are recorded on local authority sites and monuments records/historic environment records, which are increasingly being made available for public access through the internet. Archaeological sites are a material consideration in the planning process. When threatened with development appropriate measures are taken to either secure the preservation of the site (through refusal of development or integration of the site within the development – preservation in situ), or to ensure that the loss of the site is mitigated by a gain in understanding through excavation and analysis

2.4.1 Archaeology – types of material

Remains on archaeological sites consist of inorganic (glass, ceramics, metal and stone) and organic materials (such as wood, leather, textiles, plant and insect remains) and the sediments themselves. Archaeological material is found in a variety of below ground locations in urban and rural locations, as well as offshore. The nature of the sites and artefacts can vary given the date of the site, the environment in which they were buried and subsequent changes to that environment. This can affect the survival of artefacts in the ground until excavation and has implications for long-term preservation after excavation.

Most inorganic materials such as pottery and stone tools, as well as bones and shells are able to survive burial in most soil conditions; metals, however, are susceptible to corrosion in the presence of oxygen. Organic materials are also rapidly degraded through a combination of soil macrofauna (invertebrates) and micro-organisms, except where oxygen is excluded through waterlogging. As this situation is rare, occurring mainly on wetland sites, organic remains are of particular significance in providing insights into the interactions between people and their environment, especially through their use of natural materials.

Left to right

Figure 10
The wooden trackway, known as the Sweet Track (3806/7 BC) is buried beneath the path in the centre of the picture at Shapwick Heath National Nature Reserve. A high water level is maintained by an adjacent ditch. Unfortunately, because the site is buried, there isn't very much to see of the trackway. Photo: Richard Brunning

Figure 11
Reconstruction of the Sweet Track crossing a reedbed on Shapwick Heath NNR. Photo: Richard Brunning

2.4.2 Archaeology – context of material

For the vast majority of sites there is no active management of the below ground environment, and considerable pressures result from agricultural practice (i.e. ploughing, drainage, etc.) and construction. In the latter case, where development leads to excavation, artefacts are recovered and studied and then become part of museum collections (sometimes on display or, mostly, stored in the archaeological archive). When a site is preserved in situ, conditions can be controlled and monitored, although in practice this is sometimes hard to achieve.

3.0 Material decay

All materials, whether organic or inorganic eventually decay. The rate at which this happens depends on the presence of deterioration agents and the affects they have on heritage assets. Most deterioration agents do not operate independently though and changes in one will often influence another. The intensity and the speed of impact of any deterioration agent will depend greatly on the original condition of the material, its existing condition, the rate of any change and the frequency of that change.

This section of the report reviews the impact of a range of deterioration agents on the management of heritage materials (under the headings of water, inappropriate RH and temperature, light, fire, biological agents, chemical agents and physical agents). It summarises the principal decay impacts, how these impacts are monitored and some of the generally preventive methods that are used to reduce the affects of these deterioration agents. A summary at the end this section highlights areas where further work would improve knowledge and practice. These points are covered in detail in section 4. As with the previous section on the heritage sector, the purpose the section on material decay is to provide an overview of current management practice to give a clear context for understanding the recommendations made in the final part of this report.

3.1 Water

Water impacts on heritage assets come from too much, or too little water, or from its variable supply. Damage results from

- natural occurrences (i.e. flash, fluvial or coastal floods, rainfall, droughts),
- mechanical failure (burst/leaking pipes, rainwater entry),
- fire control,
- drainage.

Movable heritage

Water damage includes

- warping of wood (furniture, painting stretchers); lifting of veneers,
- formation of blooms on varnishes (e.g. paintings),
- distort of books, blocking together of papers, gelatinisation of parchment,
- running of inks/dyes (on textiles and paper),
- formation of mould if water-affected materials are not dried,
- splitting, cracking or distortion if materials are dried too quickly.

Built historic environment

Water impacts include

- damage from soluble salts in walls (crystallisation of salts in solution when the wall surface dries causes physical damage to porous materials such as brick and stone and plaster),
- weathering of exposed stonework by rainwater,
- freeze/thaw cycles to unprotected architectural remains (water in damaged stonework freezes and thaws causing expansion then contraction leading to a loss of structural integrity),
- flooding damage to earthen (i.e. cob) buildings,
- drying out of the ground (in clay soils in particular) damaging building foundations and fabric through contraction and subsidence.

Far left

Figure 12
Dungeness Sound Mirrors - water has penetrated the concrete and lead to corrosion of the steel reinforcement at the top of the structure, which has expanded causing the concrete to fall away.
Photo: Catherine Croft.

Top Figure 13
Bottom Figure 14
Rainwater goods are sometimes too small to transport water away following extreme rainfall events (see 13). In this case, from Calke Abbey, Derbyshire, the large gutters (seen in 14) filled up as the drain pipes taking the water through the parapet to the hoppers and downpipes were too small. The water in the gutters overflowed over the top of the lead flashing wetting the ceilings and walls below.
Photo: National Trust/Sarah Staniforth.

Additionally, water can increase the impacts of other deterioration agents, including

- biological attack of interior timbers in roofs and floors,
- corrosion of exterior metalwork such as gates and railings,
- corrosion of steel reinforcement within concrete (see Figure 12), iron cramps in traditional buildings or the internal iron or steel armatures of stone statues which causes the metal to expand, damaging the material fabric.

Many of these issues are exacerbated by poor building maintenance. For example, when the flashing around a chimney has failed and water seeps through, entering the walls and staining wall coverings. However, flooding from heavy rainfall can challenge even the best-maintained buildings (see Figures 13 & 14).

Archaeology

Water damage to archaeological sites from too little water or fluctuating wet and dry soil conditions include

- expansion and contraction of organic sediments and artefacts leading to mechanical damage,
- biological decay of organic remains such as wood, plant remains, pollen etc.,
- corrosion of metal objects.

An excess of water can result in

- chemical contamination from flooding,
- erosion of sites from surface water run-off and flooding.

3.1.1 Monitoring water damage

Monitoring techniques include

- installation of flood detectors in ground-floor areas and basements at high risk warn of flooding, particularly if these areas are not regularly used or visited,
- RH monitoring as water ingress may cause increase in RH (see section 3.2),
- laser surveys of building exteriors to record erosion and monitor changes over time,
- installation of boreholes (or use of remote systems) to measure water level on archaeological sites using dipmeters.

3.1.2 Managing water damage

- Water ingress risks to buildings can be reduced through regular maintenance of internal and external plumbing and waste water goods (i.e. gutters, hoppers and down pipes).
- Maintenance of drainage in land surrounding buildings including ditches, culverts, sluice gates etc.,
- Projected warmer temperatures should reduce future freeze/thaw impacts.
- Soft capping on architectural ruins provides a thermal blanket on wall-heads to aid protection from freeze/thaw (see Figure 9).
- Damage to archaeological remains from too little water is best solved by reducing drainage and limiting seasonal fluctuations.
- Monitoring is essential to demonstrate the effect of these measures.

3.2 Inappropriate relative humidity

Movable heritage

- Different materials are stable at different relative humidity (RH) levels (for example iron corrosion is retarded when the relative humidity falls below 15%).
- Low RH causes organic materials to shrink and become brittle (as in Figure 15).
- High RH encourages mould growth, and accelerates chemical changes such as metallic corrosion and the hydrolysis of certain plastics.
- Fluctuating RH causes expansion and contraction of moisture-containing material which can cause flaking, delamination and loss of material from multi-layers objects

Figure 15
RH damage to a lacquered chest at Belton House, Lincolnshire. A low RH caused the materials to dry and crack.
©NTPL/Rob Matheson

Built historic environment

- Fluctuating relative humidity causes cycles of crystallisation and dissolution that break apart pore structures in stone, brick, plaster and ceramic.
- High RH also promotes corrosion of internal and external metalwork, and steel reinforcement in concrete.

3.2.1 Monitoring relative humidity

- RH papers (containing coloured salts that react to RH changes) are used in enclosed spaces (display cases and storage boxes, particularly for archaeological metalwork).
- Basic RH monitoring of the environment inside buildings is carried using hand held equipment or continuous systems with data loggers.
- More complex equipment, linked to computers is also available, such a wireless (telemetric) systems, which provide real time results.

3.2.2 Managing relative humidity

- Inside buildings RH is controlled through air conditioning, humidification, dehumidification, or conservation heating (controlled by a humidistat rather than a thermostat).
- Ventilation and air circulation are used to introduce air at desired RH and temperature levels and to reduce localised RH spots.
- Display cases (and other forms of enclosure such as glazed frames) buffer RH fluctuations.
- RH fluctuations are also reduced by the use of desiccants (such as silica gel) within museum displays or in storage boxes, i.e. for archaeological iron.
- Identification of any changes in RH does rely on regular assessment of monitoring results and inspection of RH papers in stores.

3.3 Inappropriate temperature

Higher temperatures

- speed up chemical reactions, such as the degradation of cellulose acetate film, photographs and digital media,
- cause waxes and glues to soften (particularly when combined with high RH),
- cause outdoor wood to dry out and distort,
- increase water loss (through evaporation) on wetland archaeological sites.

Very low temperatures may cause

- embrittlement in plastics,
- frost damage to outdoor sculptures,
- freeze/thaw impacts on unprotected wall heads,
- freezing pipes in buildings (a major source of internal flood damage).

Temperature also has a critical relationship with relative humidity.

- In a room where the moisture content stays the same, a drop in temperature will cause a rise in relative humidity (moisture from the air is absorbed by organic materials).
- Conversely when temperature rises, the air absorbs the moisture from organic objects which causes them to dry out.

3.3.1 Monitoring temperature

Temperature is probably the easiest of the deterioration agents to monitor.

- It is simple and cheap to measure using commercial equipment.
- As with RH, monitoring equipment can be attached to data loggers or linked to computers produce real time results.

3.3.2 Managing temperature

- High temperature impacts on movable heritage assets are reduced by ensuring they are not placed in direct sunlight or too close to heat sources.
- Items in storage benefit from lower rather than higher temperatures.
- For chemically sensitive materials such as cellulose nitrate film and sheets and other specific plastic objects, cold storage significantly reduces deterioration rates.
- Solid walled buildings are often better adapted to respond to changes in external temperature and often stay cooler in the summer and warmer in the winter as a result of their higher thermal mass.
- Recent research has demonstrated that the use of historically appropriate shutters plus curtains can reduce energy loss in cold weather through sash windows almost as effectively as replacement with UPVC double glazed ones.

3.4 Light

Radiation of visible and ultraviolet (UV) wave-lengths causes chemical changes in a wide range of materials.

- Impacts of visible wavelengths of light include fading of photographs and loss of colour in dyes and pigments on textiles, watercolours materials and other organic materials.
- All damage is cumulative and depends on the level of light and exposure time (i.e. dose).
- UV causes of embrittlement and structural weakening of organic materials and coatings on exterior painted wood, metal and stone.
- The loss of protective coatings from light aging leads to further degradation by other environmental sources, for example water ingress leading to metal corrosion.

Figure 16
Light damage to the red wallpaper is apparent here in the Red Drawing Room at Uppark House. The red colour has been shielded from the light behind a picture (shown on the right hand side of figure 4). Where the wallpaper has not been covered the red colour has faded to brown. ©NTPL/Andreas von Einsiedel

3.4.1 Monitoring light impacts

- Light levels are monitored with light meters.
- Cumulative levels are recorded with dosimeters (e.g. blue wool dosimeters or light sensitive strips such as LightCheck®).
- Dosimeters are exposed to light for a set period of time, and then assessed visually against a comparison chart, or measured using a spectrophotometer (in case of blue wool dosimeters).

Left to right

Figure 17
Low light levels in the Sir John Ritblat Gallery, British Library reduce damage to vulnerable objects.
Photo: Barry Knight; British Library Board.

Figure 18
Blinds can be used to reduce direct sunlight, and shutters can be closed to keep all light out when the room is not used. State Dressing Room, Kingston Lacy.
©NTPL/James Mortimer

3.4.2 Managing light impacts

- All sources of light, however low will cause degradation.
- To reduce damage light levels are set to allow adequate viewing, whilst limiting the exposure of vulnerable materials (see figure 17).
- UV impacts are virtually eliminated by installing filters on high UV sources, such as windows.
- Light exposure is further reduced by preventing direct sunlight falling on sensitive materials using blinds and screens, which can be closed completely when collections not being viewed (see Figure 18).
- Light levels in collections are usually set between 50 and 150 lux (depending on the sensitivity of object classes).
- These levels are used to calculate annual light doses that permit higher light levels for shorter periods.
- Increasingly, a risk management based approach is being sought which takes greater account of fading rate and object sensitivities in order to better understand appropriate light levels and display time.

3.5 Fire damage

Principal causes of fire affecting heritage materials are

- arson,
- electrical fault,
- smoking and lighting materials (i.e. matches and candles),
- heating equipment,
- natural causes (lightning),
- hot works during construction/repair.

Figure 19
The fire damaged exterior of Uppark after the August 1989 fire, with dustbins for salvaged material.
©NTPL/Paul O'Connor

Organic materials are vulnerable because of their combustibility. High risk materials include

- paper-based collections,
- wooden objects (furniture, musical instruments),
- organic building materials, (structural wood, wooden cladding and thatch for example).

Fire-fighting generally involves the use of copious quantities of water, which may cause additional damage to other parts of the building or collection that were not directly affected by the fire.

3.5.1 Monitoring and managing fire damage

- Commercially available fire detection systems are used in most sites.
- Fire risk is reduced by controlling activities likely to cause fire, by detection, and where appropriate, suppression systems.
- Most commonly used suppression systems are water based (i.e. sprinklers), or high-pressure water mist.
- A small number of sites are using low oxygen environments in storage areas where oxygen levels are kept permanently below the level needed for combustion.
- Detection and suppression equipment needs to be sensitively integrated into historic buildings to avoid damaging fabric and detracting from the historic significance of the building.

3.6 Chemical agents

Movable heritage

Chemical pollutants impacting movable heritage assets include

- nitrogen oxides and sulphur dioxide (the latter now in declining quantities), by-products from domestic, industrial and automobile fuel combustion,
- hydrogen sulphide and volatile organic compounds (such as acetic and formic acid), generated by display materials, building fabric, machinery, visitors and the objects themselves.

These pollutants cause chemical reactions that lead to

- fading of dyes and pigments,
- tarnishing and corrosion of metal (e.g. silver tarnish from sulphides),
- embrittlement or weakening of paper and textiles,
- degradation of archaeological wood recovered from marine sites (from sulphuric acid produced from the oxidation of reduced sulphur within the wood).

Built historic environment

Pollutant impacts on the built historic environment include

- acid dissolution of calcareous building materials (from sulphur dioxide and nitrogen oxides in the atmosphere),
- sooting of buildings and black crust formation from particulates in diesel exhaust,
- corrosion of metals (including reinforcement in concrete), and increased soluble salts in stone and brick from road salting and coastal salt spray.

Archaeology

Chemical changes to buried archaeology result from

- land or groundwater contamination from industrial, agricultural or construction waste,
- use of certain fertilisers,
- de-watering/re-watering wetland sites.

These changes can

- initiate and increase corrosion (i.e. impact of agri-chemicals),
- oxidise soil minerals (leading to a loss of definition of archaeological features),
- change soil pH affecting materials such as bone and shell for example which do not survive well in acidic conditions,
- introduce oxygen into anaerobic deposits increasing biological activity (see section 3.7).

3.6.1 Monitoring chemical agents

Regular monitoring of chemical agents in museums, galleries, libraries and archives is fairly limited.

- Indoor sampling of chemical agents is carried out with sample tubes which are then sent for lab analysis, or using in situ detectors.
- To ensure that new display materials do not give off harmful gases these are usually subjected to a standard ('Oddy') test in advance of their use

There is also little monitoring of outdoor chemicals specifically in relation to historic buildings, although there are over 1500 sites monitoring outdoor air quality throughout the UK.

Figure 20
Water level can be measured in a borehole using an audible dip meter. Here Christine Elgy is taking measurements of water temperature, redox potential and pH in Droitwitch with portable probes and meters, using flow-through system to reduce contamination. Photo: Worcestershire County Council

Monitoring on archaeological sites includes

- measuring redox potential and pH (either on water samples as in Figure 20 or using in situ probes)
- chemical characterisation of water samples to identify major chemical species present.

This is still an emerging area of expertise; few sites have been monitored and most of those for short periods

3.6.2 Managing chemical agents

- The impact of chemical agents on indoor collections can be reduced by filtering or excluding polluted air, ensuring that areas are adequately ventilated or by using absorbent materials.
- Chemically sensitive materials may need to be encased to further restrict interaction with chemical agents, or isolated from other parts of the collection if they themselves are the source of pollution.
- Pollution impacts to the historic built environment have reduced due to a reduction in output of sulphur dioxide, but current urban pollutant impacts (from ozone, nitrogen oxides and black crusts from diesel) are not well understood and management strategies are under-developed.
- Corrosion impacts on outdoor metals can be slowed by coatings or managed with cathodic protection in certain cases.
- Chemical impacts on below ground archaeology can be reduced through changing land management or construction practice (for example by reducing water level fluctuations).

3.7 Biological agents

Movable heritage

- Mould, fungi and insect pests are the main biological agents which affect collections.
- Mould generally forms where relative humidity is above 65% and temperature above 10ºC.
- Insects are more prevalent and active in higher temperatures and higher relative humidity.
- Mould and fungal growth can cause surface staining, change the visual appearance of materials (i.e. of dyes) and alter the pH.
- Insect pests destroy organic material, in particular affecting wood, textiles and paper.

Built historic environment

Biological deterioration agents have similar impacts on the built historic environment. These include

- timber decay from wet and dry rot,
- damage to timbers by wood boring insects, such as the death watch beetle, (often associated with damp wood and wood rotting fungi).

Additionally, building stone can be affected by organic biofilms (bacteria, fungi, algae and lichens, with associated extra polymeric substances such as slime), and plant growth.

- Biofilms infiltrate the stone matrix and affect the movement of water
- Shrinkage and expansion of biofilms during cycles of wetting and drying can cause mechanical damage, particularly in the presence of salts.
- Plants and their roots weaken building materials, leading to moisture ingress into buildings.

Archaeology

The main affects of biological agents on archaeological sites occur on dewatered wetland sites.

- Biological agents (such as aerobic bacteria and soil fauna) degrade wood and other organic remains (such as past evidence of plants, insects, pollen)
- These impacts are intensified by disturbance of the soil, such as ploughing.
- Offshore, woodborers, such as ship worms can do considerable damage to submerged wooden material.

3.7.1 Monitoring biological agents

- Monitoring of biological agents in collections and buildings is mainly through visual inspection or the use of traps.
- This includes checking for signs of insect activity (and mould growth) and eliminating routes of entry for pests entering the building.
- This approach is known as Integrated Pest Management.
- Monitoring of biological activity on archaeological sites is almost non-existent.

3.7.2 Managing biological agents

- The impacts of biological agents on collections and historic buildings are reduced by ensuring that relative humidity and the material's moisture content are insufficient to support insects and mould.
- The risk of rot in structural timbers is reduced by ensuring the building is water tight and well ventilated.
- Eradication of infestations in collections or buildings with certain insecticides is no longer a viable option as many chemical treatments have been withdrawn because they are harmful to human health and may damage artefacts.
- There has been little characterisation of the precise role of micro-organisms or soil fauna in the degradation of buried organic archaeological material.
- Current management of biological agents generally relies on ensuring burial environments remain waterlogged, to restrict the presence of oxygen.

3.8 Physical agents

Damage to heritage assets from physical agents can occur

- during handling and transportation (i.e. dropping an object),
- from the non-routine use of areas (i.e. for weddings, parties),
- during construction work,
- from vandalism and theft,
- from natural phenomenon such as earthquakes, subsidence, landslides and lightening strikes.

Many of these causes have significant impacts, but occur infrequently or indiscriminately.

Movable heritage

Physical agents that have a lower intensity of impact but happen more regularly or are part of the management and display of heritage materials include

- wear and tear (on floors, from handling books),
- gravity, for example in heavy textiles on display,
- vibration during transportation,
- dust (see Figure 21).

The presence of dust provides a food source for micro-organisms in conditions of high relative humidity which in their turn secrete exo-polymers that bind dust particles in place and make dirt more difficult to remove. Cleaning the dust away however, can cause surface abrasion.

Figure 21
Dust on plasterwork from Chastleton House, Oxfordshire, obscures the original surface finish. Photo: Katy Lithgow

Built historic environment

Physical impacts on historic buildings include

- replacement of building materials using inappropriate substitutes,
- inappropriate renovation (including certain measures to improve energy efficiency),
- previous conservation treatments applied to consolidate walls (these may be a source of damage if they restrict the movement of moisture and salts),
- the use of inappropriate techniques to remove biofilms or pollution residues,
- graffiti and its removal.

Archaeology

Aside from accidental and wilful damage to archaeological sites, most physical impacts result from either agricultural or construction activities. These include

- ploughing and sub-soiling (it is hard to maintain a "safe" depth of ploughing),
- compression impacts from highway and building development (as in Figure 22),
- foundation construction (i.e. piling) and ground improvement techniques.

Figure 22
The impacts of construction on archaeological remains may not be readily apparent until subsequent excavation. Here a pile has caused significant damage in a cemetery in Leicester, image courtesy of University of Leicester Archaeological Services.

Offshore impacts include

- fishing, particularly beam trawling (which can damage exposed sites),
- the development of offshore wind farms,
- dredging and extraction of marine aggregates.

3.8.1 Managing and monitoring physical agents

- Most physical impacts on movable heritage can be mitigated by appropriate risk identification and adequate management of activities.
- The use of inappropriate repair materials, cleaning products and other remedial treatments on historic buildings can be mitigated through education of owners, architects, surveyors and project managers.
- Construction impacts on archaeology are mainly managed through the planning process, though farming activity on archaeological sites remains largely unregulated.
- The inaccessibility of below ground and offshore archaeological sites means that in situ monitoring has not been fully developed.

3.9 Summary of material decay management issues

Managing and mitigating the impacts of the deterioration agents described above is a complex task. The management measures described throughout this material decay section outline the basic methods used to reduce the impact of these decay agents and thus extend the lifespan of objects, buildings and sites. However, there are many issues common to all deterioration agents where further information would aid management. These include

- improved knowledge of rates of damage and thresholds for many of these agents,
- the affects of rates of change and the reversibility of these changes to different categories of collections or objects,
- improved methods to record condition and monitor change,
- better understanding of the impacts of future climate change.

4.0 Gaps in knowledge and practice

This final section of the report brings together information gathered from existing and previous strategies, and stakeholder engagement with heritage scientists and users of heritage science to identify the gaps in our existing knowledge and practice. Through this process three themes have emerged. The first two themes (understanding material behaviour and understanding environments) relate to the deterioration of heritage items and the contribution of their 'environment' in regulating and amplifying that deterioration. The final theme (improving practice) covers methods for assessing and monitoring change, considers past, present and future treatments for deteriorating materials and highlights a need for greater access to knowledge and facilities. References in [….] at the end of each topic show the main sources (i.e. existing strategies, sector consultation) of information that have contributed to the conclusions drawn.

4.1 Theme 1 – Understanding material behaviour

All materials deteriorate, and the rate and direction of change depends on their environment. Understanding these issues is essential to enhance the long term survival of these materials for the future. This theme identifies the areas where a lack of scientific knowledge is hampering current efforts to sustain these resources. It is divided into two topics, one dealing with the material decay mechanisms and rates, followed by a specific topic reviewing modern materials.

4.1.1 Understanding decay mechanisms and rates of decay – Topic 1a

Even though we have a basic, and in some cases, advanced understanding of the mechanisms involved in various processes of deterioration that affect heritage assets, our ability to determine the rates at which these processes might occur, in any given circumstance is less assured. We also lack an understanding of the 'tempo' of these processes, for example, whether they are cyclical, episodic, or slow and steady. This means that it is very hard to identify the key thresholds under which an object can be considered stable and not at risk, where over this threshold, deterioration and loss may occur.

For example, we know that very low RH will lead to a loss of moisture in organic materials leading to physical damage, but we often do not know specifically if there is a threshold RH at which damage occurs. Equally, we do not yet understand how rapidly materials respond to these changes and what impacts short-term fluctuations in pollutant concentration for example might have. These are the very things we need to know in order to be able to address basic management questions. Currently, we lack the ability to be able to answer the question "what would happen if….?"

Work is now underway to understand the deterioration mechanisms and rates of a range of materials, such as archaeological iron, parchment and textiles. The list overleaf offers examples of research areas identified during the course of consultation for this report where it is felt that further work is needed.

Figure 23
Nozzles direct desiccated air over the surface of the chloride infested hull of the ss Great Britain thereby preventing the formation of electrolyte solutions that would cause corrosion. Possible reactions were modelled in laboratory conditions to determine the effectiveness of the design. Photo: Dave Watkinson.

Figure 24
Iron gall ink corrosion has caused the loss of paper in the middle of the horse, and also created a negative image of the drawing on the facing page (not shown here). Fol 156v-157r, British Library. Photo: Barry Knight; British Library Board

Figure 25
Black dyes affect other media than just inks on books and manuscripts. Image of Akali turban prior to conservation. Height: approximately 70 cm. © Trustees of The British Museum

Movable items

An improved understanding is needed of

- acceptable limits of RH & temperature in degradation of organic materials and metals (see Figure 23),
- the impact of cumulative light exposure on different materials,
- the effectiveness of low oxygen/anoxic conditions for storage and display,
- tolerable levels of particulate and gaseous pollutants,
- the effects of high pressure water mist for fire control on organic materials,
- vibration impacts from increased visitor numbers and during transport,
- the degradation mechanisms of metal polyphenol dyes (black dyes i.e. iron gall ink – as in Figures 24 & 25),
- the degradation mechanisms of leather,
- the deterioration of biological molecular structure of natural history collections,
- methods to control of soluble/insoluble salts in collections (ceramics, glass and stone),
- how often cleaning of dust should take place – there is a need to balance impact of cleaning with philosophical and cultural issues such as perceptions of cleanliness vs. a sense of antiquity.

Built historic environment

Additional research is needed to improve understanding of

- the behaviour and methods of control of soluble salts in buildings,
- the impact of multi-pollutant urban environments and nitrogen oxides in particular on building fabric,
- the impact of the use of inappropriate materials for repair,
- the impact of non-conservation stone cleaning which can lead to acid decay and increased microbial growth,

- the interaction between moisture, microbes (e.g. biofilms) and salts in stone degradation,
- vibration damage to historic monuments,
- the impact of fire resistant treatments on the longevity of organic materials (i.e. thatch).

Archaeology

Further work is needed to determine

- the response of organic and inorganic archaeological materials to short, and long term fluctuations in water level,
- the rate of degradation of organic materials following de-watering,
- the impact of chemical agents (contamination, fertilisers) on artefacts,
- the role of micro-organisms in degradation of waterlogged buried material and factors causing increased activity,
- the impact of compression on artefacts (from construction),
- post-excavation changes to archaeological materials and mitigate their affects,
- the deterioration of archaeological soil samples; what information is lost during long-term storage,
- the impacts of exposure of marine archaeological remains.

To address these issues, research is needed at a variety of levels, including experimental work, physical and computer modelling and long-term studies (including monitoring). Analysis needs to take account of the fact that many deterioration mechanisms do not operate in isolation, but in synergy. It is also vital that these issues are considered for degraded as well as pristine items, i.e. light damage to already deteriorated archaeological pigments, or faded textiles.

Sources 1a – [4] [5] [6] [12] [13] [14] [15] [16] [19] [28] [34] [36] [39] [42] [43]

4.1.2 Modern materials – Topic 1b

Modern materials are covered in the specific topic to reflect the relative lack of current understanding and research, the inherent instability of many early synthetic materials and rapid rate of deterioration, and limited number of specialists. In many cases degradation mechanisms have not been well studied to date, and few treatment applications are available. Particular areas of priority are:

Movable items

General issues relating to most modern materials (e.g. plastics, foam, photographs, magnetic tape) include

- defining appropriate storage conditions,
- understanding the impacts of different cleaning regimes and improved methods of cleaning,
- investigation of new treatment methods and assessment of their long-term impacts,
- standardisation of methods of condition assessment (ways to record extent and rate of deterioration) for plastics. Some work underway in EU POPART project,
- improved monitoring of degradation,
- a lack of equipment/access to equipment for identification of plastics.

Specific issues identified during consultation include

- a need for better understanding of the future management and storage requirements of contemporary art, created using mixed media and non-artists materials,
- a suitable and safely removed varnish for acrylic paintings,
- methods of storage and improved understanding of the long-term stability of photographs, slides, negatives and cine film,
- the preservation of audio visual media including digital media,
- non-damaging recovery/playback methods for degraded audio visual media,
- defining ideal storage conditions for architectural drawing film,
- the conservation and long-term management of acetate and other heat set document laminates.

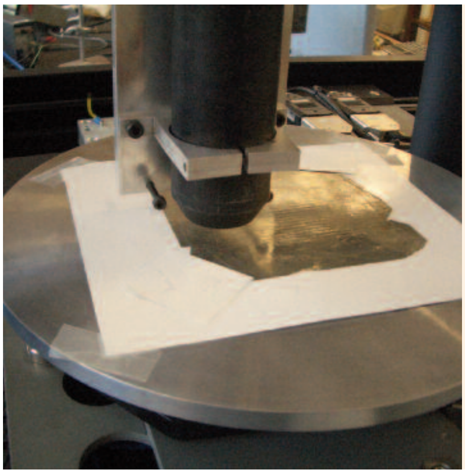

Figure 26
Surface scanning at the University of Southampton of Thomas Edison tinfoil recording of c. 1877, unplayable by conventional means. It is the British Library's earliest sound recording.
Photo courtesy of University of Southampton

Built historic environment

Further work is needed to

- understand mechanisms and rate of concrete decay,
- reduce/slow concrete decay,
- improve in situ treatment of corrosion of concrete reinforcement,
- identify more sympathetic methods of concrete repair and replacement,
- review the range and stability of aluminium and aluminium alloys used in modern buildings, i.e. windows,
- identify treatment options for plated metals,
- assess long-term stability of polymers and other materials use in cladding systems.

For certain modern materials, it may be necessary to consider the extent to which the reversibility of treatment should apply, particularly in the case of rapidly degrading material.

Sources 1b – [4] [5] [6] [12] [28] [36] [42] [43]

4.2 Theme 2 – Understanding environments

The previous theme focused on understanding the deterioration of materials. This theme looks at the ways in which environmental conditions can be controlled to reduce decay rates (topic 2a), and the responses that need to be made to adapt to climate and other external environmental change (topic 2b). To a certain extent, many of the issues covered in this theme can not be fully addressed until the research into rates and thresholds of deterioration outlined in topic 1a has been completed.

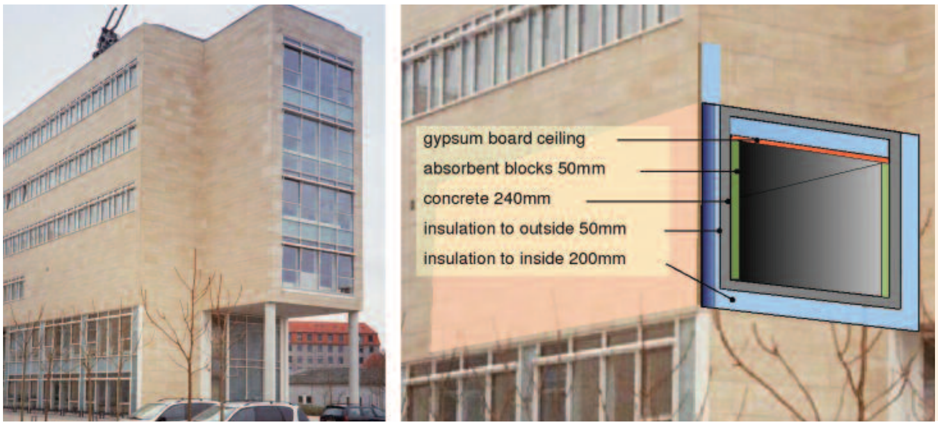

Figure 27
The archive of the Arnemagnaean Institute of Copenhagen University. The cut away section shows how the room is insulated against both the internal and the outdoor temperature, so that its temperature is always about half way between the constant 22°C of the building and the variable outdoor temperature. Image courtesy of Tim Padfield

4.2.1 Creating appropriate environments – Topic 2a

There is an increasing awareness among collections managers that current guidelines for museum, archive and library environments may be too prescriptive. Many museums do not manage to meet common standards for relative humidity and temperature for example, but without obvious deterioration to their collections. The costs of heating and air conditioning of buildings are a major expense, and these costs, as well as the need to reduce global energy consumption are driving attempts to find other, low energy, low tech methods of environmental management. A number of projects are starting to address some of these issues (such as the AHRC/EPSRC Science and Heritage research cluster project EGOR – Environmental Guidelines Opportunities and Risks – which is investigating the implications of current environmental standards on buildings, collections, and people with the view to identifying outstanding research needs).

To achieve these changes further research into material behaviour is needed (see theme 1), as well as additional understanding of

- how buildings, and historic buildings in particular, perform (see topic 2b),
- the use of natural ventilation, and other methods of passive environmental control (see Figure 27),
- the use of microenvironments to reduce deterioration.

The overall goal of future research in this area should be to achieve an appropriate compromise between permanence, cost, environmental responsibility, and the expectations of access and use.

Similarly, we need a better understanding of the environmental parameters that are critical to the survival of waterlogged archaeological remains. To improve the management of these sites we need to

- assess the level of moisture content that is sufficient to retard degradation,
- improve the characterisation of the chemical and biological composition of burial environments (both urban and rural),
- enhance characterisation of burial environments of maritime sites which are currently poorly understood.

Sources 2a – [4] [5] [6] [12] [13] [14] [15] [16] [19] [28] [36] [39] [42] [43]

4.2.2 Adapting to a changing climate – Topic 2b

Movable items

For collections, climate change brings additional challenges For example, increased temperature will lead to

- more rapid degradation,
- greater difficulties in the summer control of RH,
- more pests (new species potentially, increase in activity period) – anecdotal evidence of increased rates of insect pest lifecycles and outbreaks of mould needs to be evaluated.

Conversely, warmer, wetter winters may increase the risk of mould growth, and insect pests may not be killed off. The impacts of these predicted changes need to be modelled and used in considering issues of material decay (theme 1) and the creation of appropriate environments (topic 2a). Another cost of displaying collections is lighting and new developments in solid state (LED) and low energy lighting, as well as the phasing out of most incandescent light bulbs in 2011 will have an impact on lights used in displays.

Built historic environment

Historic buildings are vulnerable to direct impacts from climate change. Modelling of predicted changes is needed to inform adaptation to

- greater incidence and intensity of rainfall events on permeable structures,
- the impact of wind-driven rain,
- the impact of increased storminess on salt spray,
- the removal of water on individual buildings due to an increase in extreme rainwater events, i.e. capacity of rain water goods, drainage and roofs to cope with predicted storminess
- the impact of ground heave and shrinkage on traditional structures,
- the impact of flooding and drying out on traditional materials and construction methods.

Aside from direct impacts from climate change, historic buildings are also vulnerable to impacts of changes made to adapt to a changing climate. One current issue is the drive towards energy reduction and energy efficiency aimed at householders and driven through by government legislation and building regulations. Many of the recommended changes that may be appropriate for modern, insulated houses with cavity walls constructed in the last 50 years, do not necessarily improve energy efficiency in historic buildings, and can in fact be damaging to the building fabric. Unfortunately, we currently have a poor understanding of the thermal performance of traditional, vernacular and historic buildings.

Issues that need further research to facilitate more appropriate responses are

- an improved understanding of thermal transmittance (U-values) of historic materials and constructions (see Figure 28),
- better methods to understand and quantify moisture movements within permeable structures (including internal environment as well as that within walls, floors etc),
- enhanced knowledge of how historic buildings actually behave and were originally intended to behave, including resilience to climatic fluctuations,
- further calculations of the embodied energy of historic and traditional buildings.

Figure 28
Measuring U Values on a secondary glazing system. Photo: Paul Baker

Enhanced understanding of the current energy performance of historic buildings will allow design solutions to be tailored to historic buildings to improve energy efficiency, and thus sustainable use, without affecting the historic character or fabric.

Archaeology

Fundamental research on the resilience and fragility of buried archaeological materials to changes in water levels and chemistry has been identified in topics 1a and 2a. Data from this analysis will allow us to understand better, and thus adapt or mitigate more appropriately for the effects of

- greater seasonality in rainfall or increased drought conditions on wetland sites,
- increased salinity from coastal inundation,
- increased temperature around coastal waters which influences the spread of woodborers on in situ maritime timbers.

Sources 2b – [13] [14] [15] [16] [19] [28] [36] [39] [42] [43]

4.3 Theme 3 – Improving practice

The focus of this first NHSS report up to this point has been about our current understanding of the deterioration processes affecting UK heritage, the ways in which these processes can be managed and their impacts reduced. This final theme focuses on the ways in which the condition of material can be assessed and monitored (topic 3a), the conservation treatments that are undertaken when preventive measures fail (topic 3b) and the need for access to information and techniques to improve conservation practice (topic 3c).

4.3.1 Assessment and monitoring of state – Topic 3a

Most techniques used in the management of heritage assets focus on monitoring the environment as an indirect measure of the state of preservation of historic material, rather than directly monitoring a change in the condition of any given object or material. There are a wide range of available non-destructive (NDT) methods of analysis of state (from visual assessment and optical microscopy to scanning electron microscopy and x-ray diffraction), but few of these can be carried out on a large scale, away from dedicated facilities. Recently, the development of portable non-destructive tests of degradation assessment (near-infra red spectrometry for the analysis of paper degradation for example) has increased the potential for more rapid and mobile assessments to be undertaken. The dissemination of information about these new methods and their effectiveness to the sector would increase their use (see 3c).

The development of existing, new and increasingly portable methods is also needed, and particular issues raised in the course of the production of this report include

- increasing the range of NDT methods of organic analysis, for example characterisation of organic dyes and binders,
- further development of NDT systems to assess condition (such as analysis of state of deterioration of iron gall inks),
- new NDT methods to look at changes in colour of pigments and dyes,
- increasing the use of laser scanning for conservation reporting (i.e. 2D/3D surface mapping for condition analysis),
- using GIS and digital images to map and monitor biofilm development on buildings,

- transfer of techniques used in collections assessment to assess the preservation of archaeological remains,
- improving condition assessment of organic component of archaeological bones,
- further development of acoustic characterisation of deterioration state of in situ marine archaeological wood,
- further development of volatile organic compound detection equipment

Alongside improvements in assessment, there are also opportunities to enhance monitoring techniques. The development of new tools should however be focused towards low cost, easy to use and portable equipment. Where possible, these should be passive (i.e. without power or battery) and self recording, as this should reduce the loss of data from machine or human failure.

Current requirements identified within existing strategies and in consultation for this report include

- cumulative light exposure dosimeters with read outs,
- RH monitors/paper which responds when critical levels are breached (for use in storage boxes for archaeological iron for example),
- simple pollution monitors, including for volatile organic compounds (VOCs),
- continued development of methods for monitoring of dust,
- improved range of NDT methods for assessing moisture and moisture movement in walls (see figure 29),
- non-intrusive assessment of concrete and reinforcement corrosion,
- protocols for use and data collection,
- standardisation of tools and better provision of advice,
- development of methods of object-based monitoring systems for archaeological sites, i.e. rods with iron coupons that can be buried then removed at intervals to assess redox levels (see Figure 30),
- in situ monitoring of degradation products such as carbon dioxide and methane as guide to decay rates of organic archaeological deposits,
- improved monitoring techniques for maritime sites.

Sources 3a – [4] [5] [6] [12] [14] [15] [16] [19] [28] [36] [39] [42] [43]

Left to right

Figure 29
2D resistivity surveys in action New College Oxford to assess moisture in the stonework. Photo: Heather Viles

Figure 30
Corrosion products on iron coupons attached to inert plastic rods inserted into an archaeological site and removed at regular intervals can be used to assess whether the burial environment contains oxygen. The top coupon has corroded and iron staining can be seen on the plastic, although this is not present on the lower section. Photo: Vanessa Fell

4.3.2 Past, present and future conservation treatments – Topic 3b

Past treatments

Some conservation treatments used in the past, with the best intentions, have now begun to cause problems. Examples of past consolidants include soluble nylon and gutta percha (see Figure 31), coatings used on porous building materials and pesticides used to treat insect infestations. There is a need for more development of non-destructive testing methods, to help to identify the precise treatment used. We need to understand how to evaluate their impacts, find new ways to remove them and to reduce the affects that they have on the treated objects. However, this should be augmented by the collation of existing knowledge of past treatments to provide a catalogue of the range of materials used and their composition.

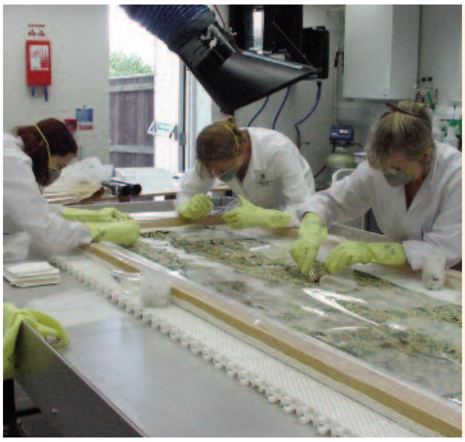

Figure 31
Conservators at the National Trust Textile Conservation Studio removing deteriorated gutta percha from one of the Cantonnieres (foot curtains) of the James II bed at Knole House.
Photo: National Trust Textile Conservation Studio

Present treatments

On the whole, conservators continue to use existing techniques unless clear problems are identified, and with the exception of the techniques mentioned above, there is little feedback on how effective treatment has been. This also reflects a general absence of long-term condition monitoring of items that have been conserved. There are, however, good reasons to re-visit current treatment options and operational procedures.

- To assess the cost/benefit of existing treatment methods; ineffective treatments can lead to higher conservation and collection management costs in the future.
- To ascertain whether anecdotal reporting of the deterioration of conserved objects are justified (i.e. recent questions about the long-term stability of PEG treated wood).
- To ensure that current treatments do not unintentionally reduce information retrieval; the information that can be recovered from heritage assets now is greater than when some treatments were devised (such as DNA from natural history collections, organic residues from ceramics).
- To consider the impact of standard procedures – for example, dusting and cleaning objects on display, or washing of archaeological finds.
- To evaluate whether current techniques will still be appropriate in a changing climate; are methods used in countries with different climates that we should look at testing for use in the UK as the climate changes – i.e. outdoor coatings.

There is a vast body of conserved material with documentation of treatment methods. An assessment of the current state of conserved objects would allow a more objective understanding to be gained about the effectiveness of various treatments. Comparison of the effects of the same treatment on similar items in different storage or display conditions would give at least qualitative data, on the impact of different environments and treatment effectiveness. A similar approach could be taken looking at treatments on historic buildings.

Conversely, there has been little documentation of which archaeological sites have been preserved in situ and few sites are monitored. A comprehensive survey of data held by local authorities would ensure that when these sites are re-developed, the present condition of the material can be compared with previous information, allowing validation of the effectiveness of the re-burial.

Future techniques

To augment existing techniques, there needs to be additional exploitation of emerging technology (often from other subject areas) to assist in conservation. Areas for potential further development include

- nanotechnology (for example, nanodeposition of calcium hydroxide for consolidation of wall paintings),
- biotechnology (further testing of microbial cleaning and consolidation of stone),
- improved methods of digitisation of paper and audio-visual material,
- further development of digital x-radiography,
- research into new coatings, particularly for outdoor metals (such as superhydrophobic materials),
- laser cleaning (and its use on a larger range of materials),
- treatments for modern materials (discussed in topic 1b),
- re-scaling of existing treatments, to be available at larger (i.e. laser cleaning) or smaller or more portable (i.e. mass de-acidification) scales.

There are also opportunities to exploit new materials for use in conservation, storage and display, such as

- lightweight, strong materials, i.e. high tensile strength thread for displaying beadwork,
- new absorbent materials to control pollution and moisture,
- inert materials that can be used in treatment to improve the retention of shape (for example in all stages of the conservation of waterlogged archaeological leather).

New treatments will also need to be developed to replace ones that are being phased out as a result of European Commission bans on certain chemicals, for example the recently announced ban on dichloromethane. The proposed restriction in the use of formaldehyde, which will have an impact on the use of formalin as a fixative for biological specimens. The need for less environmentally damaging, more natural treatments would improve the 'greening' of conservation.

For all new techniques, there needs to be improved verification processes, that includes long-term, real-time and peer-reviewed testing and monitoring, in a range of different conditions.

Sources 3b – [4] [5] [6] [12] [15] [16] [19] [28] [34] [36] [42] [43]

Figure 32
Custom built air-path XRF being used [at NMS] for non-destructive examination of a Scottish "tappit hen" pewter flagon. © Trustees National Museums Scotland

Figure 33
SEM-EDX at the Department of Conservation & Analytical Research, National Museums Collection Centre, Edinburgh. © Trustees National Museums Scotland

Figure 34
Craig Kennedy undertaking hand-held Raman spectroscopy to analyse the paint on the surface of a cast iron canopy in Rothesay, Bute, Crown Copyright, Photo: Alan Simpson

4.3.3 Increased access to tools and knowledge – Topic 3c

Many techniques used for materials analysis in heritage science have a dual application. They can provide data to aid practice and management, as well as provide information about the objects and materials themselves (see NHSS report 2). Unfortunately, many of these analytical facilitates are restricted to major institutions and universities (although the development of portable versions of standard equipment used in materials analysis provides greater opportunities to extent their use). There is also a need to ensure that people are better informed about the use of analytical techniques, what they can do, and their limitations. Currently, access to information from heritage science research is generally restricted to academic journals and conference publications, which can slow the conversion of research outputs into daily practice.

The major issues identified during the preparation of this report were

- improved awareness of existing techniques,
- better access to analytical facilities, including portable equipment,
- increased range of facilities for the analysis of organic materials,
- the need for a directory of services available – type, costs and funding opportunities.

Knowledge transfer is one of the issues which will be addressed in NHSS report 3. However, it is highlighted here because for most conservators and conservation scientists, raising awareness of, and providing better access to existing research and analytical techniques is probably as important as the development of new projects or tools.

Sources 3c – [4] [5] [6] [16] [19] [28] [42] [43]

5.0 Summary conclusions

It would be entirely wrong to conclude from the gaps identified above that the heritage sector and heritage scientists in particular lack the knowledge and tools to care for the nation's cultural heritage. It is clear from the information outlined in section 3 that we have quite a detailed understanding of the deterioration mechanisms that threaten this resource, as well as a variety of tried and tested methodologies for managing these threats, and where necessary, intervening to reduce further damage.

What we currently lack however, is a more comprehensive understanding of the rates at which most deterioration processes takes place; the thresholds at which damage occurs; how the environment can be most appropriately managed to slow the rate of change; and how a changing climate will alter the ways in which we need to manage this resource. We also need to make better use of existing and new scientific developments to assess, monitor, and treat the effects of deterioration on heritage assets. Getting a better handle on all these issues, will, in turn ensure that collections can be more sustainably managed, buildings used and adapted in the most sensitive fashion, and fragile archaeological sites protected.

5.1 Next steps – seeking your views

This report has been produced to provide the members of the National Heritage Science Strategy Steering Group with an overview of the current gaps in heritage science knowledge in relation to the management of the UK's heritage. Recommendations made here in section 4 will be used, along with information from the next two reports, to draw up a strategy for heritage science later this year.

To ensure that the gaps in knowledge and practice identified in this report accurately reflect the current needs of the heritage sector and to fulfil the recommendation of the House of Lords report that the strategy be developed from the bottom up, the NHSS steering group wishes to seek the views of heritage scientists and users of heritage science on the contents of this report. A response form is available on the NHSS website (www.heritagesciencestrategy.org.uk) in the "Our documents" section of the Document library page. Please use this form to submit your views on this report by the end of May.

A summary of responses will be produced and made available through the website and although the report will not be updated in light of the comments received, these comments will be taken on board by the steering group during the development the strategy.

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6.2 Surveys and written feedback [42]

- CHRESP Questionnaire (Cultural Heritage Research meets Practice, 8th European Commission Conference on Sustaining Europe's Cultural Heritage)
- Feedback from BM conservation staff compiled by Catherine Higgitt
- Icon Archaeology group (consultation response to ICON science group)
- Icon survey by science group
- Icon science group email survey of group chairs and science group members
- Synthesis of managing material change audience response session – provided by ICON science group.

6.2 Discussions with heritage practitioners (in addition to steering group) [43]

Anna Bülow
Barry Knight
Bill Martin
Brenda Keneghan
Catherine Croft
Catherine Higgitt
Chris Woods
David Thickett
Diane Gwilt
Dinah Eastop
Enquiry staff at NMR & CADW
Eric May
Ian Brocklebank
Ian Panter
Jane Henderson
Jane Sidell
John Feather
Joyce Townsend
Kate Lowry
Kostas Ntanos
Mark Dunkley
Mary Davis
Matija Strlic
Matthew Hall
May Cassar
Mike Corfield
Nigel Blades
Paul Garside
Rob White
Robert Turner
Sean O'Reilly
Simon Moore
Tim Yates

6.4 Web-based resources [44]

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http://jura.rcahms.gov.uk/PASTMAP/start.jsp
www.airquality.co.uk/archive/networks_home.php
www.alva.org.uk/visitor_statistics
www.bl.uk/onlinegallery/virtualbooks/index.html
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www.padfield.org/tim/index.htm
www.ukcip.org.uk
www.vam.ac.uk

7.0 Appendix 1

List of steering group members

Sarah Staniforth - Chair (National Trust)
Professor Peter Brimblecombe (University of East Anglia)
Dr Craig Kennedy (Historic Scotland)
Katy Lithgow (National Trust)
Dr Nick Merriman (Manchester Museum)
Dr Sebastian Payne (English Heritage)
Professor Mark Pollard (Oxford University)
Helen Shenton (The British Library)
Dr Jim Tate (National Museums Scotland)
Dr Heather Viles (Oxford University)
David Watkinson (Cardiff University)

7.1 Appendix 2

Differences in funding and organisational governance arrangements between the four countries of the UK.

The Government Department responsible for heritage is the Department for Culture Media and Sport (DCMS), but many of its functions and funding for heritage are devolved to the Scottish Government, Welsh and Northern Ireland Assemblies. Each devolved administration is responsible for direct funding of national museums, galleries, libraries and archives. Responsiblities for sector guidance and the provision of statutory functions (for example, listing buildings) as well as funding arrangements for respective national lead bodies are different within each adminstration.

	England	Wales	Scotland	Northern Ireland
Museums	MLA	CyMAL	Museums Galleries Scotland	Northern Ireland Museums Council
Galleries	MLA	CyMAL	Museums Galleries Scotland	Northern Ireland Museums Council
Libraries	MLA	CyMAL	SLIC	LISC (NI)
Archives	MLA*	CyMAL	SLIC	LISC (NI)
Historic Buildings	English Heritage	Cadw	Historic Scotland	NIEA
Archaeology	English Heritage	Cadw	Historic Scotland	NIEA

Abbreviations

MLA - Museums, Libraries and Archives Council
CyMAL - Museums Archives and Libraries Wales
Cadw - Welsh Assembly Government's Historic Environment service.
SLIC - The Scottish Library and Information Council
LISC (NI) - Library and Information Services Council, Northern Ireland.
NIEA - Northern Ireland environment agency (archaeology & buildings)

* Although archives as a sector are part of the remit of DCMS, The National Archives is sponsored by the Ministy of Justice.

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