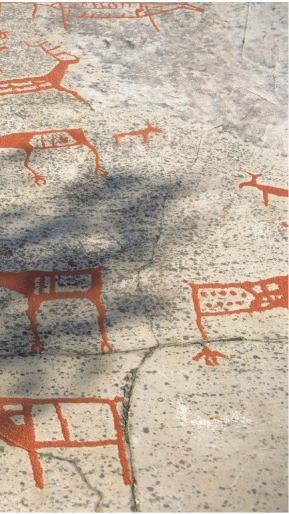


Climate Change and Cultural Heritage in the Nordic Countries





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Anne S. Kaslegard

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Preface

This publication is a result of the project *Effekter av klimaendringer på kulturminner og kulturmiljø* (Effects of climate change on cultural heritage sites and cultural environments). The project was established in 2008 as a collaboration between the cultural heritage administrations of seven Nordic countries: Iceland, Greenland, the Faeroe Islands, Denmark, Sweden, Finland and Norway. The aim of the project has been to assist the cultural heritage administrators in meeting the anticipated climate change and to strengthen Nordic collaboration and network building between the Nordic cultural heritage administrators.

The Nordic countries have common challenges in respect of observed and future climate change and its consequences for the management of heritage sites. At the same time, the Nordic countries individually have limited resources to tackle these issues. Nordic collaboration on this project has therefore given a unique opportunity for exchanging information and making use of the combined knowledge and expertise in the field. The project has also strengthened the personal and institutional network between the cultural heritage administrators in the participating countries.

The project has primarily been financed by the Nordic Council of Ministers through the Working Group for Nature, Outdoor Life and Cultural Environment (NFK), which has changed its name during the project period to the Terrestrial Ecosystem Group (TEG). The project has been intended to contribute to achieving the goal of the Nordic Council of Ministers' Environmental Programme 2005-2008 to initiate a more focused effort for information about the significance of global climate change for nature and cultural heritage in the Nordic countries. The project has also been relevant for the goals of the Environmental Programme 2009-2012, primarily the goal of alleviating negative effects of climate change.

Those who have participated in the project are:

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The project has delivered four reports (in Norwegian language), which may be found on the website http://www.riksantikvaren.no/Norsk/Prosjekter/Klima_og_kulturarv/, or obtained by applying to the library of the Directorate for Cultural Heritage. The publication *Climate Change and Cultural Heritage in the Nordic Countries* is based on this work.

As well as producing reports and the website, the project organised the Nordic conference *Klima og kulturarv – fortid moter fremtid* (Climate and cultural heritage – the past meets the future) in November 2009 in Oslo. An introductory film was produced for this conference that has since been shown on various occasions. In connection with the project meetings, a number of smaller seminars have been held with presentations related to climate change and cultural heritage sites. The project has been met with great interest from various quarters and we hope it will contribute to improving knowledge about the theme of climate change and cultural heritage among both cultural heritage administrators and others.

Oslo, November 2010

Anne S. Kaslegard
PROJECT MANAGER

Summary

Climate Change and Cultural Heritage in the Nordic Countries contains the main results of the project *Effekter av klimaendringer på kulturminner og kulturmiljø* (Effects of climate change on cultural heritage sites and cultural environments). The publication consists of two parts, part one of which discusses the anticipated effects of climate change on cultural heritage sites and cultural environments in the Nordic countries. Part two addresses what consequences the climate change will have for the management of heritage sites and includes the project group's recommendations for handling these consequences.

The content of the first part is based on available research and knowledge about how a changing climate will physically affect cultural heritage in the Nordic region.

Buildings of heritage value will be exposed to increasing strain, since most materials will deteriorate more quickly in a warmer and damper climate. Rising sea level, more storm flooding and increasing coastal erosion could threaten coastal buildings in vulnerable areas. In addition to the gradual change over the course of time, climate change will lead to more frequent extreme weather, which can cause acute damage to both heritage buildings and other cultural heritage sites.

Conservation conditions for archaeological material will be affected as well, but there is some uncertainty about what effects can be expected and how significant they will be. Archaeological sites in different conservation contexts – in air, earth, ice, snow or water – will be affected differently.

The growing season for plants and trees in the Nordic countries will be extended, and this will affect cultural environments and landscapes, for example by accelerating vegetation growth and by raising the tree lines. Extreme weather such as storms and heavy rain could affect both urban and rural cultural environments and landscapes.

Part two of the publication addresses what consequences climate change will have for the management of heritage sites and cultural environments, in the form of more damage, increased loss, changes in conservation conditions for heritage sites and new archaeological finds. The project recommends a number of measures to prevent and to handle these consequences, including:

- *Identification, mapping and documentation of cultural heritage sites and cultural environments that are particularly vulnerable as a result of climate change*
- *Repairing climate-induced damages to cultural heritage sites*
- *More intensive maintenance of heritage buildings and management of vegetation*
- *Archaeological excavations and documentation*
- *Coastal defence measures*
- *Monitoring*
- *Developing knowledge and expertise*
- *Response planning that takes climate change into account*

Climate-related change in other social sectors will also affect the management of heritage sites and cultural environments. An increased focus on energy efficiency is already a great challenge to heritage buildings. In the energy sector, developing renewable energy sources such as wind power, hydropower, geothermal energy and ground source heating will have an effect on archaeological heritage sites, cultural environments and landscapes. Climate-related change in industries such as agriculture, forestry and tourism will also affect heritage sites and cultural environments, as will the development of infrastructure and changing land use as a result of climate changes.

In order to meet the climate-related changes in other sectors, the project's recommendations include the following:

- *Cross-sector collaboration and collaboration with different industries*
- *Work on legislation, regulations and standards*
- *Information and advice*

Introduction

Cultural heritage includes in itself knowledge about adapting to climate over the course of time. People have dressed according to the weather and have developed ways of life and of building houses that have been adapted to local climate conditions. Today we can see that climate change could make it more difficult to protect the traces of the life and work of earlier times. Not just climate change in itself, but also society's handling of the climate issue will affect our cultural heritage in various ways. Owners and administrators of heritage sites and cultural environments will therefore face a greater challenge in future in taking care of our cultural heritage in a changing climate and in a society where everyone must help limit further climate change.

Climate change will have a direct effect on heritage sites, through physical changes in the environment that change the conservation conditions for the materials at the site. We have only seen the beginning of the physical changes. Mean global temperatures have risen by just over 0.7°C in the course of the last century, and the global sea level is rising by just over three millimetres a year. The anticipated effects on heritage sites in the Nordic region in the future will be caused by a warmer and damper climate, rising sea level and more frequent extreme weather.

Even though a changing climate will have a direct effect on heritage sites and cultural environments, we can also see that climate change affects heritage sites in a more indirect way. Firstly, measures to reduce greenhouse gas emissions will affect the whole of society, including the cultural heritage field. Secondly, different sectors' adaptation to a changed climate could also affect cultural heritage. Unlike climate changes, which occur slowly and whose effects are mostly felt only after a long time, society's response to climate change is already having consequences for the management of cultural heritage.

This TemaNord publication is based on the following reports published by the project *Effekter av klimaendringer på kulturminner og kulturmiljø* (Effects of climate change on cultural heritage sites and cultural environments):

1: *Klimaforhold og klimaendringer i Norden* (Climatic conditions and climate change in the Nordic countries)

2: *Kulturminner, kulturmiljø og landskap i Norden* (Heritage sites, cultural environments and landscapes in the Nordic countries)

3: *Effekter av klimaendringer på kulturminner og kulturmiljø* (Effects of climate change on cultural heritage sites and cultural environments)

4: *Konsekvenser av klimaendringer for forvaltningen av kulturminner og kulturmiljø, og anbefalte tiltak* (Consequences of climate change for the management of heritage sites and cultural environments, and recommended measures)

The project's first report covers climatic conditions and prognoses for climate change in the Nordic countries and was written by Hans Olav Hygen of the Meteorological Institute in Oslo. The report has created a basis for further work on the project. To summarise, it shows that a future rise in temperatures is expected throughout the Nordic countries, but with large regional differences. The greatest increase in temperature will occur in winter and the greatest warming will be in the Arctic regions, where a temperature increase of 3-4°C is expected by the middle of this century. It appears that other areas can expect warming of about 1-1.5°C compared with the present climate. As regards rainfall, for the region as a whole an increase of about 10% is expected annually. However, the west coasts of Norway and Finland could see an increase of 20-30% during the winter. It appears that heavy and extreme rainfall will occur more often throughout the Nordic region. There will also probably be somewhat stronger winds in the region in the future, although wind prognoses are very uncertain.

In the report from the Meteorological Institute, the historical climate and anticipated climate for seven selected heritage sites, most of them on UNESCO's World Heritage List, are given special attention. Later in the project, these sites have been used as examples of how cultural environments are affected by climate and climate change. The examples are included in this publication.

The project's second report is a brief introduction to the categories *built environment, archaeological heritage sites and cultural environments and landscapes* in the Nordic countries.

The third report gathers together knowledge about the effects of climate change on heritage sites and cultural environments in the Nordic countries. However research into this area is currently limited. The research project Noah's Ark¹ is an exception, however, so results of this project are often referred to. A major new research project under the EU's 7th framework programme, Climate for Culture (2009 – 2014), is in progress, but as yet there are no results available. The report is otherwise based on smaller research projects, reports and articles from different sources that can offer information in different ways about how climate change will affect heritage sites and cultural environments. Many of the issues raised in the report regarding possible effects of climate change have not yet been sufficiently addressed.

The fourth and final report assesses the direct and indirect consequences of climate change for the management of heritage sites, and recommends various measures for preventing and handling the negative consequences.

The TemaNord publication *Climate Change and Cultural Heritage in the Nordic Countries* consists mainly of the results of the project as they appear in Report 3 and a somewhat abbreviated version of Report 4.

The following definitions have formed the basis of the work: Cultural heritage sites are all traces of human activity in our physical environment, including places associated with historical events, beliefs and traditions. Cultural environments are areas where several heritage sites form part of a larger entity or context. Landscape is defined as in the European Landscape Convention as an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors. In this context, however, only landscape that has been influenced by people is of relevance.

¹ Noah's Ark (2004-2007) was a research project under the EU's 6th framework programme that aimed to study the effects of future climate change on the material cultural heritage. The project developed among other things a vulnerability atlas of Europe based on a combination of climate models and models of how climate factors affect the decomposition of different materials. The results are illustrated in maps showing changes in the near future (defined as the period 2010-2039) and the distant future (2070-2099), both compared with the recent past (1961-1990). The models are based on IPCC's scenario A2, which assumes that greenhouse gas emissions continue to increase in the next century.

Part 1

Effects of Climate Change on Cultural Heritage Sites and Cultural Environments in the Nordic countries

1. Effects of climate change on built heritage

The climate subjects the built environment to impacts such as humidity, temperature fluctuations and wind. All building materials will be subject to deterioration over the course of time and climatic conditions will be of decisive significance for the rate at which this occurs. Climate change associated with global warming will therefore influence the conservation conditions for cultural heritage buildings and other cultural heritage sites in a built environment. How biological, physical and chemical decomposition processes can be expected to be affected is discussed in sections 1.1, 1.2 and 1.3. A warmer climate also means that the permafrost in Arctic regions will melt and that the sea level will rise. This could impact on the built environment in the affected areas and is the subject of sections 1.4 and 1.5 respectively. In addition to the gradual changes that occur over long periods, climate change will also mean more extreme weather events. This could lead to acute damage to buildings and structures of cultural heritage value, something that is discussed in section 1.6.

1.1 Biological decomposition

Climate change will subject wooden buildings and building elements to an increased risk of rot and pests, while increased biological growth could lead to the faster decomposition of all kinds of buildings.

Timber and other organic building materials, such as turf, straw and seaweed, are naturally decomposed by different kinds of bacteria, fungi and insects. The activity of these organisms is greatly dependent on climatic conditions such as temperature and humidity. Biological impact on organic material is therefore a type of damage that will be affected by climate change, as pointed out by the UNESCO World Heritage Centre (2007), and others. Timber has long been an important building material in the Nordic countries. This section, which covers the biological decomposition of built environments under the influence of the climate, will therefore largely concern itself with the decomposition of timber.

The biological decomposition of timber normally requires a certain amount of humidity. Moisture is already one of the biggest challenges when it comes to damage to buildings (Lisø and Kvande, 2007). The building damage archive that was established through SINTEF Byggforsk's research programme *Klima 2000* shows that two out of three cases of damage to buildings in Norway arise in connection with the building's climate shield, that is to say its roof, outer walls and floor against the ground. With more rainfall in future, the effects of humidity on buildings will become an even greater challenge.

Fungi

Moisture is a basic precondition for the growth of fungi in buildings. Fungal spores are found practically everywhere



Damage by rot to the roof of a medieval loft in Fyresdal, Telemark. (Photo: Inge Aamlid © Directorate for Cultural Heritage, Norway)

and, when conditions are right, fungi of different varieties will attack timber as a source of nutrition. Species that break down cellulose cause dry rot, which characteristically causes the wood to turn brown and crack into cuboidal chunks. Fungi that break down both cellulose and lignin cause wet rot, which causes the wood to become soft and fibrous (Hole and Olstad, 2008c). There is a danger of attack by the rot-inducing fungi if the water content of timber exceeds about 20% of dry weight. In timber that has already been attacked, some species can survive in a hibernating state during much drier conditions. Rot can also occur at a relative atmospheric humidity of over 85%. Normally the fungi that cause rot can grow at temperatures from 4-5°C to 35-40°C.

The research project Noah's Ark (2007) has developed a model of how the decomposition of wooden structures outdoors due to rot will be affected by higher temperatures and increased rainfall in the future. The model takes into account air temperature and water penetration of the wood, it assumes that the wood must have a certain degree of moisture for the rot-inducing fungi to grow and that fungal growth begins 48 hours after water penetration. The type of wood used as an example is spruce. The results show that we can expect up to 50% increase in the risk of outdoor rot in northern Europe in the course of the next century. Here *increased risk* means an increase in the presence of conditions that allow the fungi to grow. According to the Noah's Ark maps, Norway, Sweden, Finland and to some extent Iceland and the Faeroe Islands will experience the greatest increase in risk.

However, these maps do not give much coverage to the Arctic areas. Warming in the north is expected to be considerably higher than the global average. In the dry, cold Arctic climate of Greenland and Svalbard, biological decomposition generally proceeds slowly. We can expect, however, that the biological decomposition of buildings will increase in the future as a result of the warmer, more humid climate (Mattsson and Flyen, 2008). Investigation of five protected buildings in Svalbard, mostly old trapping cabins, showed considerable fungal and rot damage, which was progressing

Gammelstad "Church Town" (Luleå) vulnerable to rot

The "church town" of Gammelstad is the site where the town of Luleå in Sweden was founded in 1621. The site has been the centre of the parish since the 14th century. Nederluleå Church, which was built in stone at the end of the 15th century, is on high ground, surrounded by more than 400 small timber buildings. The use of such buildings can be traced back to the 16th century, while the oldest examples standing here today are from around 1700. They were built by the populace for accommodation when visiting the church, for markets and for public meetings, since the considerable distances involved made it difficult to get to church and back on the same day. In this thinly populated area, the big church festivals became an important social event and this tradition continues to some extent even today. The church town also includes both official buildings and private homes built of wood.

The small buildings around the church are of timber and most have a facade of wooden panels. Maintenance has to some extent been poor and many of the buildings have rot in both the panels and the timber structure. Meltwater from the hill finds its way down streets and alleys and make the timber near ground moist, which leads to damages.

Gammelstad is near the coast of Norrbotten. Climate prognoses to the middle of this century indicate a substantial increase in average temperatures: about 3°C in winter and about 1°C in summer. Precipitation is expected to increase by about 10-20% in the autumn and winter, mostly in the winter. This will mean warmer and damper winters, wetter autumns and more meltwater in spring. General warming has already occurred, according to measurements taken over the period 1991 to 2005. Even today, the changes can be traced through finds of the true dry rot fungus (*Serpula lacrymans*), for example, which was previously unknown in the area.



Gammelstad "church town" with Nederluleå Church in the background. (Photo: Jörgen Runeby © Swedish National Heritage Board)

A review of the damage was carried out in 2007 to document the extent of rot in the buildings. This project has been concluded, but a follow-up is needed to review accumulations of rainwater and meltwater. Systematic snow clearing is now carried out throughout the winter, to minimise mechanical damage to the facades and problems with meltwater right up to the buildings.

Other measures that can be carried out include improving drainage in the area, meaning a better developed system of ditches and run-off chambers, gutters and drainpipes. Information about the maintenance of old timber buildings will also be important for taking care of Gammelstad.

rapidly. Local solar warming of the buildings can cause much more favourable conditions for fungal growth than would be expected from the temperature.

With increasing humidity and higher temperatures, the occurrence of other types of fungi may be expected to increase. Black mould appears as black spots on painted or untreated wood surfaces. Such mould does not cause decomposition of the wood to any great extent, but is mainly an aesthetic problem (Hole and Olstad, 2008d). Mildew can occur on various kinds of materials that are wet, and it causes discoloration and a poor indoor environment (Mattsson, Hole and Olstad, 2008b). However, mildew does not cause decomposition of wood in the same way as the fungi that cause dry or wet rot.

Even though, generally speaking, the risk of rot will increase with more rainfall and higher temperatures, there are substantial differences between various types of wood and materials. The heartwood of pine, and particularly of slow-growing pine with a high resin content, is less liable to rot than the outer part of the trunk (Godal, 1994). The

heartwood of oak is even more resistant to rot than that of pine. In the built heritage, there has long been a tradition of using specially-chosen materials for different purposes. Different types of wood, different dimensions and different parts of the tree have been used for the purpose to which they are best suited. For those parts of the building that are exposed to rain, such as panels, roofing shingles or windows, the preference has been for the heartwood of slow growing trees, so as to avoid rot. The way in which the material is taken out of a log and how the boards are laid on the building, for example, are also significant for how resistant the building will be to damage caused by rain and snow. In earlier times, buildings were tailored to local climate conditions by sorting material for different purposes and by developing local building practices. Lisø and Kvande (2007) stress the need for local climate adaptations in all building activities, so as to avoid damage to buildings. They point out that good building traditions and practice adapted to local conditions have to some extent been sacrificed to standard and cost-saving solutions.

Pests

Insect larvae that live by eating wood can attack buildings and other cultural heritage sites made of timber. Such pests are dependent on certain climatic conditions in order to survive and reproduce, and it is therefore probable that climate change can have an effect on their geographical range.

The larvae of the house longhorn beetle (*Hylotrupes bajulus*) need high temperatures to develop, so the species is only prevalent in the southern, coastal parts of the Nordic region. The optimum temperature for activity and development is around 28-30°C, while the larvae stop eating wood when the temperature falls below 10°C. Increased temperatures in the future could therefore provide these larvae with better living conditions. Mattsson (2009) concludes that at present there are no signs of the house longhorn beetle spreading in Norway. It is pointed out, however, that higher winter temperatures could give the beetles better opportunities for development in areas that are warm in summer, and that in such a case spreading would occur locally, as an extension of already established house longhorn beetle areas. In addition to higher temperatures, a higher relative humidity in the future will also favour the development of house longhorn beetle larvae.

In addition to the house longhorn beetle, the woodworm (*Anobium punctatum*) and carpenter ant (*Camponotus sp*) are the insects that cause the most damage to wooden buildings in our part of the world (Mattsson, 1996). Various carpenter ant species are found in coniferous areas all over the Nordic region. These ants do not eat timber, but they can make nests in rotten timbers in buildings and spread out into the rot-free areas. Climate change will increase the risk of rot in timber buildings, and thereby also increase the risk of carpenter ant colonies becoming established in the rotten timbers.

Woodworm are found in all the Nordic countries except Greenland, primarily in coastal regions. Insects that damage wood are regularly introduced into Greenland, but as a rule they quickly die out and do not become established. Woodworm require a damp environment to reproduce and develop and are often found in woodwork in cellars and basements. Increasing moisture problems in woodwork due to increased rainfall and atmospheric humidity could therefore influence the spread of this pest. House longhorn beetles and woodworm can only survive outdoors in timber in mild winters. As temperatures increase, more pests could overwinter, which could lead in turn to more damage.

Biological growth

Buildings that are not regularly maintained will become colonised by biological organisms such as mosses, algae and similar. Biological growth on buildings and structures can be expected to increase with rising temperatures and increased rainfall (Hole and Olstad, 2008a). Algae, lichens and moss do not necessarily damage the building, but they retain the damp and can therefore help to create moisture-related damage such as rot and frost expansion. More vegetation around buildings creates more humidity and slows the drying-out of the outer skin of the building, thus leading to the growth of fungi and algae. Not only timber buildings, but also brick and concrete

can be affected by decomposition caused by biological growth, primarily through plant roots growing into and expanding cracks in the wall. Increased biological growth will affect not only buildings, but also whole cultural environments and landscapes. This is discussed in more detail in section 3.1.

1.2 Physical decomposition

Climate change will bring a somewhat reduced risk of frost damage in southern and coastal parts of the Nordic region towards the end of the century, while the risk will increase in higher altitudes and more northern areas. The risk of expansion damage from salt crystallisation may increase throughout the Nordic region. Clay and materials that contain clay will be exposed to increased decomposition.

Physical disintegration is the decomposition of a material into smaller fragments without changing its mineralogical or chemical composition. Frost damage is a frequent cause of physical decomposition of brick buildings in the Nordic countries. Another form of physical disintegration is due to salt crystallisation, which can both spoil appearance and bring about a gradual fragmentation of the building materials by expansion.

Frost damage

Frost damage occurs when water collects in cracks and pores and freezes. When water freezes into ice it expands and can therefore cause building materials to crack (Haugen, 2008a). The effects on built cultural heritage sites include flaking plaster or the cracking and fragmentation of pointing, stones, bricks and concrete. Whether it is the mortar or the bricks in a wall that freeze into pieces will depend on the characteristics of the particular materials. Masonry that is exposed to moisture because of poor drainage, cracked pointing or damaged plaster will be particularly liable to frost damage.

Various attempts have been made to review the changing risk of frost damage as a result of the anticipated climate change. The number of freeze/thaw cycles that occur during the course of a year can be used as an indicator for the risk of frost damage. A freeze/thaw cycle means that the temperature falls below freezing point and then climbs above 0°C again. Noah's Ark (2007) estimated that the risk of frost damage occurs when the temperature falls below -3°C. In this project, a freeze/thaw cycle has therefore been defined as fluctuations between below -3°C and above 1°C.

We see the greatest number of such fluctuations in climates that are often around 0°C. Currently Iceland is the Nordic country that has the most freezing point transitions, but that country will probably experience a slight reduction in the number of transitions in the future. Towards the end of this century, Denmark can expect the greatest reduction in the number of freeze-thaw episodes, and thereby a reduced risk of frost damage to buildings. In the short term, up until the middle of this century, it does not appear that there will be great changes anywhere in the Nordic countries. In the long term it is mainly the northern and higher altitude areas that can

expect more frost damage. This will apply to parts of Norway, Sweden and Finland that previously had cold winters, with few freeze-thaw episodes during the course of the year. Even so, the change here is expected to be moderate. In the Arctic regions, on the other hand, greater changes can be expected. Narsarsuaq in Greenland currently experiences 7-8 freeze-thaw cycles a year, but this is expected to more than double by the end of the century (Noah's Ark, 2006).

Wet-frost (Noah's Ark, 2007) occurs when freezing takes place immediately after rain, and this is another indicator that has been used to note the danger of frost damage. Since frost expansion and damage is caused by water in pores and cracks, it will make a great difference if it has recently rained when it freezes. Noah's Ark counts the number of episodes of wet-frost as the number of days in the course of the year with rain and temperatures over 0°C, immediately followed by days with average temperatures below -1°C. Risk mapping for wet-frost gives slightly different results for frost damage than mapping freeze-thaw cycles. The tendency for future risk of frost damage to be reduced in southern and coastal areas nevertheless remains the same.

If we take into account both freeze-thaw cycles and wet-frost, it is large parts of Finland, the inner and northern part of the Scandinavian Peninsula and the Arctic regions that are most likely to experience a greater risk of frost damage. However, changes from the normal period to the near future are insignificant, and changes up to the end of the century also appear to be moderate.

Salt crystallisation

Salt crystallisation is another cause of the physical decomposition of bricks and mortar. According to Noah's Ark (2007), it appears that the incidence of salt crystallisation will increase in Finland and the south-eastern part of the Scandinavian Peninsula towards the end of the century as a result of climate change. This is because a lower relative atmospheric humidity in summer will increase the potential for salt crystallisation. In Iceland, on the other hand, the incidence is expected to fall.

Others have emphasised the significance of increased rainfall for the incidence of salt crystallisation (Haugen, 2008b). More rain may cause an increased risk of salt crystallisation because the water that penetrates structures transports salts back out to the surface. These salts may come from the building materials themselves or they may have come from outside. When the water evaporates, the salt crystallises and expands, and the pressure thus created in the pores of the material can lead to expansion damage. This becomes visible as powdering or flaking of the wall and a white salt deposit. On the basis of increased rainfall, the risk of salt crystallisation will increase in most of the Nordic region.

Decomposition of clay and stone that contains clay

As a building material, clay is very sensitive to the effects of moisture, and it is reasonable to suppose that wattle and daub walls and other materials containing clay will be exposed to more decomposition in a damper climate. In Denmark, the use of wattle and daub and limed wall panels between the

timbers has been extensive in old half-timbered houses. The lime plaster protects against rain, but if water gets through to the clay, this rapidly decomposes. Another example of the use of clay as a building material is in old brick walls where clay has been used in the mortar to save lime. Clay has also been used to plaster walls on the inside, and cellar walls in particular, if they have been plastered with clay, are vulnerable to moisture penetration.

Noah's Ark (2007) has mapped out the risk of damage to sandstone with a clay content and shows that the decomposition of such building materials will increase during the course of this century, as a result of the anticipated increase in rainfall. If stone containing clay is exposed to damp, it will swell and eventually decompose. However, the extent of stone containing clay as a building material is limited in the Nordic countries, so this is not expected to be a significant problem for heritage buildings here.

1.3 Chemical decomposition

Climate change will increase the risk of corrosion of metal structures and building elements, but lessening acid rain will counteract this effect. The chemical decomposition of stones like marble and limestone that contain carbon will probably increase. More humidity could also increase the risk of concrete cracking.

Chemical decomposition involves a change in a material's chemical composition. Stone, metal and wood are all subject to chemical decomposition, often together with physical and biological processes. Only in extremely cold and dry areas will physical disintegration of stone occur alone, because as long as water is present there will also be chemical disintegration. Climatic factors such as humidity and temperature are important prerequisites for the chemical processes that cause materials to decompose.

Metal

A number of metals are particularly prone to chemical decomposition. In heritage buildings in the Nordic countries, metal building elements include for example iron beams, iron bolts and wall anchorages in stone or brick walls, and roofing and guttering of copper or zinc. Technical and industrial heritage sites, as well as memorials from the Second World War, often consist of iron and steel installations and mechanical devices or concrete structures with iron reinforcement.

Chemical decomposition causes metals like iron, copper and zinc to slowly corrode away. Rust in iron building elements also causes damage to the building. Rust created by the corrosion of iron has a greater volume than the iron and can therefore split surrounding stone or masonry. Corrosion in metal structures is influenced by two significant environmental factors, salt deposit and acid pollution, particularly SO₂ (Noah's Ark, 2007). These environmental factors work together with climatic factors such as temperature and atmospheric humidity.

Particles can carry salt water from the sea far inland on the

wind and lead to corrosion of metal structures and metal parts of heritage buildings (Noah's Ark, 2007). A model based on the Hadley Centre's prognoses for wind to the end of the century shows that salt deposit on land may increase somewhat, mostly in areas where the wind is already carrying a great deal of salt. This applies to the coasts of the Barents Sea, North Sea and Baltic Sea. The change compared with the present will however be small, and there is great uncertainty regarding future wind strengths and directions.

It is nevertheless estimated that corrosion of zinc caused by salt will increase in all areas with salt deposit from the sea or road salting (Noah's Ark, 2007). The reason for this is that higher temperatures tend to increase zinc corrosion. We see the same trend for copper and lead, although less clearly.

Corrosion of iron and bronze caused by SO₂ pollution depends on both temperature and relative humidity, with temperature as the most important factor (Noah's Ark, 2007). If we assume an unchanged level of SO₂, corrosion is expected to increase throughout the Nordic region. However, if the model takes into account the reduction in acid rain from SO₂ pollution since the reference period (1961-1990) and the fact that this is expected to be reduced even further, the negative effects of climate change are offset.

Concrete

Cultural heritage sites of reinforced concrete are also vulnerable to various processes of decomposition. However, corrosion of reinforcing iron is considered to be the cause of most damage to concrete structures (SINTEF Byggforsk, 2009). This corrosion may be due to carbonation or caused by chlorides.

Carbonation occurs when carbon dioxide from the air and water reacts chemically with constituent parts of concrete. This reduces the pH value, which leads in turn to the reinforcing iron rusting. Rust has a significantly higher volume than iron and can therefore cause the concrete to crack and flake. The carbonation process occurs most quickly if the relative humidity in the concrete is between 40 and 60 per cent, while both drier and wetter concrete structures carbonise very slowly. If increased rainfall causes concrete to become damper, this could increase the risk of carbonation and decomposition of cultural heritage sites where concrete is used.

Chlorides in concrete are another significant cause of corrosion of the reinforcing iron. The chloride salts enter the concrete from either sea water or road salting. In coastal areas where climate change will lead to an increase in sea spray, with salt water penetrating the concrete, problems with corrosion of the reinforcing iron may occur. The same will apply to areas where climate change increases the need for road salting.

Concrete can also suffer serious damage as a result of alkaline reactions, although this is a much smaller problem than the reinforcement corrosion (SINTEF Byggforsk, 2007). An alkaline reaction is a chemical reaction that leads to the formation of a gel, and when the gel takes up water and expands, cracking in the concrete will occur. This reaction requires water and the extent of the damage increases with the water content of the concrete. Field studies have shown that cracking is greatest in the parts of concrete structures most exposed

to damp and that the chemical reaction becomes faster as the temperature increases. It is therefore reasonable to suppose that a wetter and warmer climate could also lead to a certain increase in damage to concrete as a result of alkaline reactions.

Stone

Stones that contain carbon, such as marble and limestone, are also vulnerable to chemical decomposition. Attempts have been made to calculate how the surface of such rocks is eroded by rain (Noah's Ark, 2007). Acid rain and the dry deposit of pollutants in between rainfall will increase the decomposition, but the effect of the rain itself is the most significant. In the recent past (1961-1990) the level of decomposition has been about the same in the Nordic region as in the rest of Europe. This is, however, expected to change due to the anticipated changes in rainfall patterns in the future, with more rainfall in northern Europe and less in the south. While the chemical decomposition of cultural heritage sites made of stones like marble and limestone is expected to decrease in southern Europe, it appears it will increase a little in the Nordic region.

Other materials

Timber is chemically decomposed by oxygen in a slow process that requires warmth and light, in particular ultraviolet radiation. Salt can also contribute to the chemical decomposition of timber materials, as has recently been revealed by research on expedition cabins in the Antarctic (Farrell et al., 2004). This revealed damage in the form of defibration of the timber, something that can occur rapidly when high concentrations of salt come into contact with damp timber. In Greenland and Svalbard, less sea ice and more wind could lead to increased concentrations of salt particles from the sea reaching wooden buildings in coastal areas, causing such decomposition.

Generally speaking, climate change in the form of increased temperatures and humidity will lead to a certain increase in the risk of chemical decomposition of the various materials of which cultural heritage may consist. This is not always the case, though. For old glass made of potash, such as medieval windows, the situation is different (Noah's Ark, 2007). The model shows that a slight reduction in the speed of corrosion of this material may be expected throughout the Nordic region. This assumes a constant level of the pollution that causes this decomposition, so that temperature and relative humidity become decisive.

1.4 The thawing of permafrost

Thawing of permafrost due to increased temperatures could cause settling and damage to cultural heritage buildings. Reduced permafrost and increased rainfall could also make mountainsides more vulnerable to landslides, which could threaten built heritage in some places.

Permafrost is defined as frozen ground that does not thaw in summer at least two years running. Only the topmost layer, known as the active layer, thaws, while the ground further

down is frozen year round. In the Nordic region, permafrost is found in Greenland and Svalbard and in high mountain areas on the Scandinavian Peninsula.

In areas with permafrost, warming as a result of climate change could cause building foundations to settle and deform (Instanes, 2005). However, damage to structures, buildings and foundations in areas with permafrost can often be due to other factors, such as poor design or construction. Climate change could accelerate the problems that have already occurred because of such conditions. The greatest problems will probably arise in places where permafrost is

not continuous – that is to say areas where the permafrost is broken up by areas without permafrost.

One corner of the 1773 Blue Church in the old town of Sisimiut (Holsteinsborg), in Greenland is slowly sinking, which is probably due to changes in the permafrost. In Svalbard too, many protected buildings and structures could be affected by changes to the permafrost. In some of the brick buildings in the Russian settlement of Pyramiden, for example, large cracks have appeared in walls, which may be due to permafrost movement, or other factors pointed out by Instanes (2005).

Bergen and Ribe – two historic cities at risk from rising sea level



The quay of Bryggen in Bergen under water.

(Photo: © Bryggen Foundation)

Bryggen, a World Heritage site, is the old harbour district of Bergen, with roots that go back to before the Hanseatic period. The wooden buildings that stand here today were rebuilt after the great fire of 1702, in the medieval tradition. The buildings are laid out as rows of timber warehouses with narrow passages between them, and the protected area now consists of 61 buildings.

The foundations of the buildings at Bryggen consist of pine beams, laid crossways directly on the ground. Gradually, as the timbers have rotted, the foundations have settled and sunk. Below the buildings are deep layers of accumulated material. Drainage has lowered the water table and led to decomposition of the organic material in these layers, which has caused the ground to settle even further. While the ground below Bryggen is sinking, Bergen will experience a considerable rise in sea level, estimated at between 53 and 108 centimetres, over the next century. Bryggen has been flooded by storm tides several times in recent years, and as the sea level rises, this will happen more often.

A comprehensive restoration programme for the World Heritage site was started in 2000. As each building is restored and given new foundations, the foundations are now being raised by about 60 centimetres in relation to sea level, to compensate for the many years

of sinking. When this is complete, Bryggen will be above the highest storm tide level so far recorded in Bergen. The sea level will continue to rise in the future, however, and the discussions about how to protect Bryggen and Bergen have not yet been concluded.

Ribe is not on the World Heritage list, but as Denmark's oldest city it has a unique history of 1,300 years of urban development. Ribe lies in flat marshland on the west coast of Jutland and over the years it has been subjected to disastrous storms and rising water levels. On 11 October 1634, Ribe experienced the worst storm in its recorded history. The water entered the beautiful, five-naved cathedral *Vor Frue Kirke*, which is four metres above the normal water level. The maximum water level during the flood was measured at 1.6 metres inside the church and is now marked on one of the columns.

Today this part of the coast is probably one of the best protected in Denmark, with altogether more than 20 kilometres of dikes. The dikes are about 12 metres across at the base and 2.5 metres at the top and rise about 7 metres above the normal water level. They were first built in 1924-25 and later extended in 1978-87. Jutland also has its own storm flood contingency measures. The cultural heritage site of Ribe is therefore now well protected against the rising sea level and storm tides.



Ribe with the cathedral in the background.

(Photo: Ingoll, 2006. Licence: GNU Free Documentation Licence)

In permafrost areas, rising temperatures and increased rain and snowfall, coupled with increasingly frequent storms, will enhance the probability of landslides and rockfalls on unstable mountainsides (Instanes, 2005). The protected mining and aerial cableway structures in the mountainsides of Longyearbyen in Svalbard are examples of cultural heritage that could be lost in the event of a landslide.

1.5 Rising sea level and increased coastal erosion

A rising sea level and increasing storm tide heights could lead to damage to cultural heritage buildings. Sea level rise will also contribute to increased coastal erosion, which could threaten built heritage near the coast in vulnerable areas. In Arctic regions, the shrinking area of sea ice will lead to increased coastal erosion.

The global sea level is currently rising at the rate of more than three millimetres a year. Global warming will further increase sea level, although estimates of how much the sea will rise over the next century are uncertain (Hygen, 2008). In the Nordic countries, there will be marked regional differences in the effects of the rising sea level. The main reason for this is that the land is rising in some places, but is stable or sinking in others. The effects of the rising sea level will also depend on topography. Where the land is flat, an increase in sea level will affect a greater area than where the land rises steeply from the sea. More frequent flood tides and increased coastal erosion are other possible effects of climate change.

Rising sea level

In many parts of the Nordic region, heritage buildings near the sea could be threatened by rising sea level in the longer term. Of the Nordic countries, it is Denmark that will be most affected by the rising sea level, both because most of the country is sinking by 1-2 millimetres a year and because the country is flat. The same applies to the southern coast of Sweden. Observations in the Faeroe Islands indicate a relative increase in sea level, that is to say an increase in relation to a fixed point on land. In Norway too, there are large areas where the land is not rising, or where it is rising so slowly that it will not counter the effect of rising sea level. This applies mainly to west Norway and the coast from Lofoten northwards. In the longer term, these areas will also see a rise in sea level, although in many places the topography will make them less vulnerable.

Coastal erosion

A rise in sea level will also lead to an increase in coastal erosion (IPCC, 2007). Climate change could also change ocean currents so that new areas will become more vulnerable to erosion. Coastal erosion is a natural process in which land masses are worn down by waves and wind. How vulnerable a coastal area is to erosion depends on its topographical and

geomorphological characteristics (Aunan and Romstad, 2008). A relatively steep coastline consisting of hard rock cliffs will be at little risk compared to a low lying area of loose sediment.

Coastal erosion represents a serious threat to built heritage in affected parts of the Nordic countries. One of the vulnerable areas is the coast of Denmark, which consists of sand and loose material. On the west coast of Jutland, the medieval Mårup Church had to be taken down in 2008 to save it from being carried out to sea. The church was then only nine metres from the cliff down to the sea, while in 1793 it had been about 500 metres away from the coastline (Dam, 2009). Measurements indicate that the speed of erosion is increasing, although the reasons for this are not fully understood.

In Sweden, the regions of Skåne, Halland, Öland and Gotland are particularly vulnerable to coastal erosion. As in Denmark, these areas will also experience a rise in sea level that will increase the problem. Coastal erosion is also a problem in the Faeroe Islands, where many old dwelling sites have been lost to the sea. The people of these islands have long known that the sea level is rising. In the village of Kirkjubøur, for example, the tradition is that when a new boathouse is built, it should be one alen (two feet) higher up than the old one (Arge, 2010).

There is also considerable coastal erosion in Greenland, Svalbard and Jan Mayen. In many parts of the Arctic area, however, the beaches get a certain amount of protection from sea ice. Sea ice protects the coast from the impact of waves in the winter, and the remaining ice on land in the summer can also limit coastline erosion. One result of the warming that is occurring in the Arctic is that the extent of the sea ice is shrinking. This has already been observed, especially in summer (Hygen, 2008). The shrinking sea ice alongside the land could expose many lengths of coastline in the Arctic to more wave erosion. The majority of cultural heritage sites in the Arctic areas are near the coast and are therefore particularly vulnerable. Some buildings of heritage value have already been lost to erosion and many more are at risk of disappearing. On the island of Jan Mayen, for example, some of the building remains of the research station *Østerrikeren* from the First International Polar Year of 1882-83 have recently been lost to erosion. Shrinking sea ice and more extreme weather will probably increase the rate of the existing erosion and speed up the decomposition of cultural heritage sites.

Storm tides

From time to time, storm tides cause damage to buildings and infrastructure on the coast. A storm tide is caused when an area of low pressure combined with an onshore wind pushes water up towards the coast at the same time as the tide is at its highest. The anticipated increases in both sea level and storm activity will lead to higher storm tides being measured in the future (Klimatilpassning Norge, 2009). This means that damage to heritage buildings caused by storm tides could occur more frequently. With a higher sea level in the future, less extreme tides could also lead to damage.

1.6 Effects of extreme weather

An increase in extreme rainfall episodes could lead to the more frequent incidence of damp in buildings and an increase in damp damage. The risk of flash flooding, landslides and avalanches will also increase, but the majority of cultural heritage buildings will probably not be particularly vulnerable to landslides and avalanches.

The incidence of extreme weather is expected to increase throughout the Nordic region over the next century. Prognoses for future rainfall indicate that the incidence of extreme rainfall will increase (Hygen, 2008). Future wind conditions are less certain, but there are indications that strong winds will occur more often over most of the Nordic region, especially in winter. Extreme wind and rainfall could therefore impact on cultural heritage buildings, causing damage. Extreme weather can also lead to flooding and landslides, which could also affect built heritage.

Precipitation

Large volumes of rain falling over a short period could cause water penetration and damp in buildings, leading to damp-related damage. For example, gutters that have not been designed for large volumes of water could frequently overflow during heavy rain.

Generally speaking, the amount of snow will be reduced in the Nordic region in the future because of higher winter temperatures (Hygen, 2008). Snow load problems on buildings will therefore be reduced in the longer term. In some areas, however, especially high-altitude and northern regions, an increase in winter precipitation could lead to more snow in the near future. Here increased snowfall and heavier, wet snow on roofs could cause greater stress to buildings than previously. Nevertheless there are many conditions, such as wind speed and direction, the location of the building and the design of the roof, that contribute towards the amount of snow on a roof, and therefore how great the load will be (Flyen, 2008). In the worst case, snow loads can weaken the building's structure, causing damage or collapse. Older buildings often have an over-dimensioned load-bearing structure and can tolerate increased snow loads, unless they have already suffered weakening or damage. However, buildings with large roof surfaces, such as old industrial or agricultural buildings, will be vulnerable to increased snowfall. More recent, modernistic heritage buildings with flat roofs could also be at risk.

Landslides and avalanches

Generally speaking, heritage buildings are not especially vulnerable to avalanches and landslides. On the contrary, old buildings are usually located in places with little danger, while more recent desires for sunshine, views and nearness to cities have meant that more recent buildings sometimes have been built in higher risk locations. However, if climate change leads to avalanches and landslides in places where they

Flooding of Verla pulp mill and cardboard factory

About 160km north west of Helsinki lies the settlement of Verla, where Verla pulp mill and cardboard factory was built in 1872 beside the logging centre of Mäntyharju. The timber processing plants were built by waterways and waterfalls, where the water provided a source of power and a means of transporting the logs. Verla also offered the opportunity of transporting the finished product by railway, which was built in 1870. This old industrial area is on the UNESCO World Heritage list because it is a uniquely well-preserved example of rural industrial production of wood pulp and cardboard, an industry that blossomed in northern Europe around 1900. The production buildings as we see them today were built in brick in the late 1890s. This industrial community also has a director's house, a sauna, a mill, community centres and workers' accommodation built of timber.

Power stations have been built at the Verla Falls several times, the first as early as the 1920s. The latest power station dates from 1974. The water above the falls has also been dammed, resulting in a higher water level. This high water level, combined with increased rainfall, now represents a threat to Verla's world heritage buildings. Between now and the middle of the century, winter precipitation is expected to increase by around 10%, while summer rainfall will be reduced.

Long periods of rain are especially critical for Verla. The water level in the power station's chutes rises high above the windows of the pulp mill and water penetrates the structure. New high water levels have been ever more frequent in recent years. Preventive measures have been set in motion, but the risk of flooding is imminent.



Flooded factory building, Verla.

(Photo: Pertti Peltola, Verla Mill Museum)

have not previously occurred, heritage buildings may also be affected.

Landslides and avalanches are often triggered by specific weather situations, and historical analysis shows that precipitation is the most frequent trigger (GeoExtreme, s.d.). This applies especially to avalanches, but also to landslides. More frequent days of heavy rain are therefore expected to result

in an increase in the number of landslides and of mud slides, where there is more water than soil in the slide. In parts of the Nordic region that will experience higher winter snowfall, the incidence of avalanches will increase. Floods and high water levels lead to erosion and increased pore pressure in clay, which can in turn increase the incidence of landslide. On the other hand, increased overgrowing of former pastures could reduce the risk, both because of root systems binding the soil together and because trees and bushes hinder avalanches.

In order to be able to assess the extent to which an increased risk of landslide might represent a threat to cultural heritage sites, an overview is needed of which cultural heritage sites are in risk areas. This would require geological maps that show landslide risk to be combined with geographical data on cultural heritage sites. If this is to provide results that could give clues about the risk to specific cultural heritage sites, the map must have a high level of detail. Such landslide risk maps have only been developed for a few places, in connection with development projects. The GeoExtreme project believes that more detailed geological surveying is needed in order to produce better maps and models. An overview map of Norway indicates that it is mainly the country's four northernmost counties that will experience the greatest increase in the frequency of landslides as a result of future climate change. This is also the part of the country that has the fewest protected buildings per square kilometre. This means that, even if the risk of landslide increases in this part of the country, the likelihood of a protected building being affected is small.

Flood

Flood can lead to great surface and structural damage to heritage buildings. Historical settlements near streams and rivers, situated there to take advantage of water power, will be particularly vulnerable and water penetration of the buildings could lead to a danger of fungal attack and corrosion of metals.

Floods can be caused by heavy rain, rapid snow melting, or a combination of the two. A high level of moisture in the ground is also significant, especially for flooding caused by heavy rain. If the earth is already saturated with water, there will be a greater run-off of surface water than if the earth had been dry. A future increase in temperature will mean less snow and more rain in winter in large parts of the Nordic region, apart from high altitude and northern regions (Hygen, 2008).

According to flood scenarios, generally speaking flooding caused by snow melting in spring will thereby be lessened (NVE, 2009). Rain and winter flooding, on the other hand, will increase. Higher temperatures mean more water vapour in the atmosphere, which will in turn increase the probability of more intense local rainfall. In small drainage basins, this could cause bigger floods, while the slower moving nature of larger drainage basins will reduce this effect. This means that the risk of flooding will increase especially in small waterways in steep terrain. In many places, the landscape's natural ability to create reservoirs has been lessened by drainage and urbanisation, which increases the risk of flooding. With the aid of a flood zone map combined with geographical cultural heritage data, it is possible to map out which cultural heritage sites are vulnerable to flooding.

Even though heritage buildings may be damaged by flooding, traditional materials like wood, brick and stone tolerate exposure to water better than many modern building materials. The greater permeability of older buildings also ensures natural ventilation, which is a great benefit with regard to drying out walls and floors after water intrusion. An English research project that has investigated the drying process in wet brick walls confirms this (Cassar and Hawkings (ed.), 2007). Old brick walls consist of materials that are open to diffusion and so naturally take up and release humidity, and this is an advantage when it comes to drying out after a flood.

Wind

Future projections for wind are subject to a great deal of uncertainty (Hygen, 2008). There will probably be more strong winds and storm activity than before, and this could cause structural damage to buildings. Increased wind strengths are expected in the winter especially, the time of year when the greatest increase in precipitation is also expected. This will result in an increase in driving rain, which strikes the buildings horizontally, increasing damp levels in walls and the risk of damp-related damage. According to Noah's Ark (2007), northern parts of Europe, and especially the North Atlantic areas, will experience more driving rain in the future. On the other hand, more wind could also help to dry out buildings when it is not raining. It is, however, difficult to say how great this positive effect will be in relation to the negative effect of driving rain.

2. Effects of climate change on archaeological material

The environment in which archaeological material is found is of great significance for how the material is protected. When the climate changes, the conservation conditions for the archaeological material in situ may also change. There is, however, a great deal of uncertainty regarding what effects can be expected and how great these effects may be. Climate change will also affect archaeological sites in different ways,

depending whether they are in air, in earth, in ice, in snow or in water. This will often be of greater significance than what the archaeological material itself consists of. This section on the effects of climate change on archaeological material is therefore divided according to the conservation context in which the material is located.

Runestones in Jelling must be protected against the climate

The Jelling World Heritage site in Denmark includes a medieval church, two royal burial mounds and two runestones from Viking times. The church is built over the remains of earlier wooden churches that have stood on the same spot. The site reflects not only the transition from heathen times to Christianity, but the runestones also express the uniting of the country, the incorporation of Norway into the realm and the “Danes” as a people. The burial mounds are said to have held the remains of King Gorm the Old and Queen Thyra and are supposed to have been built by their son, King Harald Bluetooth. The runestones stand in front of the church, open to the sky. The small stone was placed by Gorm and the larger one by Harald Bluetooth. The text on the larger stone reads: “King Harald bade these memorials to be made after Gorm, his father, and Thyra, his mother, the Harald who won the whole of Denmark and Norway and made the Danes into Christians”. The text of the small stone reads: “King Gorm made these memorials after Thyra, his Queen, Denmark’s adornment”.

The condition of the stones causes concern and in 2006 the National Museum took the initiative to carry out a comprehensive survey to assess the stones’ condition and decide how best they could be secured for the future. The report of their work may be found at <http://www.natmus.dk/sw65205.asp>. Damp, combined with temperature fluctuations around 0°C, have led to frost damage, which was identified as the greatest damaging factor for the two runestones. In the

long term, global warming will mean that Denmark experiences fewer freeze-thaw cycles. In future therefore, stone heritage objects will be less vulnerable to frost damage than they are today. However, the present situation of the runestones at Jelling is assessed to be “extremely critical” for the small stone and “worrying” for the large one. It has therefore been decided to erect a protective building around the two Jelling stones to protect them from further climate impact, while eliminating any need to move the stones.



The two runestones at Jelling will be protected by a building.
(Photo: Heritage Agency of Denmark)

2.1 Archaeological material above the ground

Increased temperatures will reduce the risk of frost damage to stone materials at archaeological sites in southern and coastal parts of the Nordic region. In northern and high altitude areas, the risk will increase. More rain and snowfall will lead to increased chemical decomposition of stone, while increased biological growth may accelerate biological decomposition. The extent of storm damage will probably increase.

Archaeological material currently found exposed is mainly of stone, since less durable materials are broken down and disappear relatively quickly. Archaeological sites conserved above ground level include building ruins and various types of burial memorials, rock art and runestones. These sites are exposed to wind and weather and the climatic conditions are very significant for the physical and chemical disintegration that occurs. The climate also has an effect on biological growth on and around the sites, which can contribute to the decomposition of brick and stone.

Frost damage

Frost damage due to expansion is probably the most important form of physical decomposition to which archaeological sites in the Nordic countries are exposed. Even though ruins and buildings are exposed to the same types of physical decay,

ruins can be even more vulnerable because they lack a protective roof. Runestones, rock carvings, cave and rock paintings are also vulnerable to environmental effects, because even minor decomposition and flaking of the surface renders them less readable. As with stone and brick buildings, archaeological stone materials in southern and coastal parts of the Nordic region will probably be less vulnerable to frost damage towards the end of the century. In northern and high altitude areas, higher winter temperatures will lead to more freeze-thaw cycles and thereby a greater risk of frost damage (Noah’s Ark, 2007).

Chemical decomposition

Chemical decomposition is another cause of disintegration of archaeological stone materials. Some types of rock are more vulnerable to chemical decomposition than others. Noah’s Ark (2007) has estimated that the decomposition of marble and limestone in the Nordic countries will increase somewhat in the next century because of an expected increase in rainfall. A Swedish study of long-term damage to runestones has shown that such decomposition does not occur evenly over the course of time (Löfvendahl et al., 2001). The 22 runestones in the study represented four different types of rock – gneiss, limestone, sandstone and granite. All the rock types show that the rate of damage has become considerably faster over the last hundred years or so compared with previous

centuries. After a long period of limited chemical decomposition, the stones now appear to have reached a point where disintegration is beginning to accelerate and physical decomposition is increasing. The study also shows that the extent and duration of damp are important external factors affecting decomposition. This can increase chemical decomposition, biological colonisation and physical decomposition in the form of frost damage. A damper climate will thereby probably lead to increased chemical and biological decomposition of all types of stone, while the extent of additional damage from frost expansion will depend on temperatures.

Biological decomposition

Biological decomposition of stone occurs through the effects of plants or animals. Plant growth is strongly dependent on climate, and the growing season in southern parts of the Nordic region has become longer in recent decades (Nordic Council of Ministers, 2009). Increased temperatures in the future will lead to an even greater extension of the growing season. This will probably increase problems of overgrowing on and around archaeological sites. Movement of the tree line to a higher altitude could have a negative effect on archaeological sites that have previously been free of trees. Overgrowing can cause the sites to become less visible and can also lead to further damage, caused by root growth for example. Root damage is caused when plants or trees send roots into cracks in stone or walls, so that as the roots grow they cause greater cracking. Plants and trees on and around cultural heritage sites also cause more damp and slow the drying out of rainwater and dew, and can therefore lead to damp related damage such as frost damage (Bjelland and Helberg (ed.), 2006).

Storm damage

Extreme weather can impact on archaeological sites in various ways. Storms can blow down trees, causing their roots to be torn up, along with earth and stone. When this happens close to archaeological sites, these too can be damaged. After a storm in Ribe county in Western Jutland in December 1999, damage was recorded at 17% of the sites that were inspected in the forest areas affected by the storm (Hertz and Andreasen, 2000). The damage was partly directly caused by the storm and partly by the subsequent clear up. When the storm Gudrun hit south Sweden in January 2005, 75 million cubic metres of forest was felled and damage was done to cultural heritage sites over a wide area (Riksantikvarieämbetet, 2007). In the hard-hit county of Kronoberg, more than 3,200 out of 11,000 registered archaeological sites were damaged, including more than 1,500 prehistoric burial sites. These examples show that storm damage to archaeological sites can be considerable. The extent of storm damage to forests can be expected to increase in the future due to climate change (Solberg and Dalen (ed.), 2007). The damage will be caused by an increased frequency of strong winds, wetter earth providing poorer anchorage for roots, less frozen subsoil in winter and trees that are heavy with wet snow. It is therefore reasonable to expect a certain increase in the number of archaeological cultural heritage sites that are damaged or destroyed by the felling of trees in storms.

2.2 Archaeological material in the ground

Climate change will bring changes to the water balance in the ground, which can have both positive and negative effects on archaeological material. The rising sea level, less sea ice in Arctic regions, more frequent intense rainfall and stronger winds could all lead to increased erosion of archaeological sites.

Many remains of the settlement, transport, trading activities and religious cults of former times lie buried beneath the surface of the ground. In the open air, organic material is quickly broken down, while in the ground it can be conserved for a long time if conditions are right. Therefore archaeological finds consist not only of inorganic material like stone, metal and glass, but also remains of timber, bone, leather and textiles, among others. Even though different materials will undergo different biological, physical and chemical decomposition processes, generally speaking archaeological material will be best preserved in earth that is saturated with still, fresh water. In unsaturated zones too, the water content in places will be high enough to provide good conditions for preservation. It is also very important for preserving archaeological material that the environment around it is stable. If the environment changes, the chemical balance that has been maintained between the object and its environment is disturbed, leading to renewed decomposition. Climate change can have consequences for archaeological heritage items that are preserved in the ground, through changing water balance in the soil, increased erosion and more frequent extreme weather.

Decomposition processes

Different types of archaeological materials are broken down in different ways. Timber in the ground can be quickly broken down by fungi, if oxygen is available (Huisman (ed.), 2009). If the timber lies in wet earth that dries out periodically, the decomposition of the wood will be accelerated by both the length of the dry periods and how frequently they occur. In wooden items lying in low-oxygen, water-saturated earth, bacteria can break down the cellulose, so that finally only the cell walls remain. The waterlogged archaeological timber keeps its outer form, even though 50 to 80 per cent of its dry weight may have disappeared. If it dries out, it will crumble and decay in a very short time. Water circulation appears to have a marked effect on bacterial decomposition, and timber and other organic materials are therefore best preserved in earth that is saturated with still water. Metal items made of iron, copper and copper alloys will also be well preserved in water saturated ground, because of the lack of oxygen. If the water contains salt, however, it will cause these metals to corrode, as will an environment with a low pH value.

Changes in the water balance

When the earth dries out, cracks appear in its layers that can admit oxygen. With an oxygen supply, microorganisms will begin to break down organic materials and metal will corrode. If the earth dries out, therefore, this accelerates the decomposition of archaeological material. In other words,

Troubled times for Kirkjubøur

Kirkjubøur was the seat of the Faeroe Islands' bishops from the time it was founded in the early 12th century up until it ceased to be an independent bishopric in 1557. From 1153/54 it came under the archbishopric of Nidaros. Today it is the site of the only historic remains on the islands that can be said to be truly monumental – buildings and ruins of plastered walls built of stone and a local lime mortar. These monuments do not represent the timber building tradition of the Faeroe Islands, a culture of building in wood based on Norse precedents from Viking times and the Middle Ages. Instead, the buildings at Kirkjubøur reflect their link with the Nordic and international church and international society. They underline the significance and power of this church centre. It was from here that the streams of Nordic and European culture entered the present day Faroese society.

The first of the monuments we now connect with the bishopric is the ruined *Múririn* or Magnus Cathedral, which was built around 1300. It is a Gothic building with obvious connections to western Norwegian church building of the same period. We also find *the parish church*, often called Olav's Church, which was built in the 13th century. This is the only medieval church on the islands that is still in use and. Archaeological investigation has revealed signs of older buildings beneath and beside this church. The ruin of a church built around 1420, *Likhús*, with its churchyard has now been greatly affected by coastal erosion. The ruins of the bishop's palace extend to about 2,500 square metres, consisting of two parallel walled buildings flanking a paved yard. The yard was closed off to the north and south by walls. The eastern side was the bishop's residence, while the western side was used for working buildings and storage. Above the stone cellars of the eastern side there still stand medieval timber buildings, of log construction.

Recent surveys and measurements of the walls of the ruined cathedral have shown natural decomposition caused by wind and weather, freezing and thawing, partly caused by water and damp penetration in openings in the masonry. In spite of the building's coastal location, there is no sign of problems caused by salt in the masonry. The sea salt is washed off by the frequent rain. Even so, climate change will make *Likhús'* walls more vulnerable to weather and sea. A rockslide in 1772 caused a great deal of

damage to the settlement and the anticipated climate changes will also involve a risk of further occurrences in the future.

Kirkjubøur has always been vulnerable to coastal erosion. Local folk tales maintain, for example, that what is now the islet outside of Kirkjubøur was connected to the mainland until a great storm in the early 1600s. The fact that the buildings are now so close to the coastline also clearly indicates the same. Partial coastal defences have therefore become necessary in more recent times. With the sea level rising, the sea will become an increasing threat to the remains of this old bishopric. But Kirkjubøur is only one of the locations on the Faeroe Islands where coastal erosion must be regarded as a major problem, because the islands' permanent settlements have always been on the coast.

In 2008, a policy for the conservation and maintenance of the ruins was devised. One of the measures will be various forms of coastal defences. However, a basic prerequisite for conservation work in general will be to record areas vulnerable to erosion where valuable cultural heritage sites are in danger of being lost.



Kirkjubøur with the remains of *Likhús* church in the foreground, the white parish church to the left, and the ruins of Magnus Cathedral to the right.

(Photo: Símun V. Arge)

the water content of the earth is of vital significance for the conservation conditions of any archaeological items or materials it may contain. In nature, the water balance is determined by rainfall, surface and river drainage, evaporation and the formation of natural reservoirs. How much water is contained in such reservoirs depends in turn on geology, topography and vegetation. Climate change will affect the water balance in the soil, but according to the UN climate report (IPCC, 2007), there is as yet little research into what effect this will have on groundwater, which is part of the water balance.

If the water balance and groundwater conditions change, this can have both positive and negative effects for the conservation of archaeological material in the ground. In the Nordic region, a general increase in annual rainfall is expected. This could lead to a higher water content in the earth, which

would be positive for the archaeological items that lie in it. However, a number of Nordic areas will have lower summer rainfall, which may cause periods when the ground dries out, with increased decomposition of archaeological material as a result. Research by the Massachusetts Institute of Technology (Chandler, 2008) shows that changes in the water table can be much greater than would be suggested by rainfall change alone. The study shows both that a moderate increase in annual rainfall can cause a great increase in the groundwater reservoirs, while a moderate reduction in annual rainfall can cause a dramatic reduction in groundwater. The exact effects of increased or reduced rainfall are, however, dependent on a number of other factors, such as soil, vegetation and when and how long it rains. There will therefore be considerable local variations in the effect of climate change on water content in

the ground, and consequently for the conservation conditions for archaeological material.

Erosion



Medieval ruins are threatened by river erosion in Húsavík.

(Photo: Símun V. Arge)

Erosion is a natural and constant process in which land masses are worn down by waves and ocean currents, wind, running water or glaciers. Climate change could, however, contribute to increased erosion. The sea level is expected to rise in the years to come because of increased melting of ice caps and glaciers, and because the volume of the water becomes greater as the oceans become warmer. A higher sea level could accelerate the rate of coastal erosion (UNESCO World Heritage Centre, 2007). In the Nordic countries, areas with little or no landrise, or where the land is sinking, will be particularly vulnerable. These areas are discussed in section 1.5 in connection with built heritage that is vulnerable to erosion. A decrease in the extent of sea ice could lead to increased coastal erosion in Arctic areas, which will affect a number of prehistoric settlement sites in Greenland and more recent archaeological remains from whaling and other activities on Svalbard and Jan Mayen. Even though prognoses of wind conditions are uncertain, there are indications that the Nordic area will experience somewhat stronger winds in the future (Hygen, 2008). More wind could increase erosion of archaeological sites by the coast and in vulnerable dry areas with thin soils (Blankholm, 2009). Heavy rainfall and strong winds can trigger landslides, which might also affect archaeological sites. An increased frequency of heavy downpours will lead to increased erosion of sites (English Heritage, 2008). Floods can destroy archaeological structures and wash out the soil along riverbeds and streams. Erosion can reveal new archaeological finds, but the exposed material will then be at risk of being eroded away within a short time.

The effects of salt

Salt accelerates corrosion in items made of iron, copper and copper alloys (Huisman (ed.), 2009). With a rising sea level and more frequent storm tides, salt water penetrating the ground may affect archaeological material. If climate change creates more fluctuations above and below the freezing point, thereby increasing the need for road salting, this salt could also damage archaeological items, especially those made of metal

(Berghäll and Pesu, 2008). The Swedish research project *Fynd och miljö* (Finds and the environment – Nord and Lagerlöf, 2002) has investigated about 4,500 bronze and iron items in museum collections and 300 newly excavated metal finds. The results show that the decomposition of metals in the ground has increased and that items being excavated today are generally more corroded than those dug up fifty to a hundred years ago. The effect of salt is one of many factors that have contributed to this development, which appears in general to have been more affected by human activity than by climate change.

2.3 Archaeological material in frozen ground and snow patches

Rising temperatures lead to the thawing of permafrost and will make conservation conditions for archaeological material in Arctic regions considerably poorer. Melting snow patches will reveal new archaeological finds.

Archaeological items that lie in frozen ground or below snow and ice can remain well protected for a long time. If the ground or ice thaws, there will be major consequences for the archaeological material. In addition to the effects of reduced permafrost and melting glaciers, having less frozen ground in winter can also affect the preservation of archaeological sites.

The thawing of permafrost

In the Nordic region, permafrost is found mainly in Greenland and Svalbard, but also in high mountain areas on the Scandinavian Peninsula. Excavations in Svalbard have revealed 17th century bodies that still had remains of hair and skin intact (Barr, 2009). The bodies had partly been freeze dried in the cold, dry climate and partly preserved in the permafrost. The Arctic areas are the part of the world where global warming is greatest and where the greatest temperature increases are expected. Melting of Greenland's inland ice, a lessening of sea ice and the warming of permafrost areas has all already been observed (Hygen, 2008). A warmer climate will mean a deeper active layer that thaws in summer, and will thus make the conditions for preserving archaeological material considerably poorer. When the ground is not frozen, landslides on slopes also become more likely.

Melting snow patches

Higher temperatures have led to the melting of glaciers and permanent snow in high Alpine areas both in the Nordic region and in other parts of the world in recent years. This has resulted in a number of finds of archaeological material on and beside the snow patches (Farbregd, 2009; Finstad and Pilø, 2010). With glaciers, however, few finds have been made, since the movement of the glaciers would have largely destroyed any archaeological material. The melting has so far led to few finds in Greenland and Iceland. In the high mountains of southern and central Norway, on the other hand, several hundred items have been found, as well as some finds in the northernmost

Ilulissat Ice fjord in a warmer climate

Qajaa in Greenland is an example of how permafrost can secure perfect conditions for preserving archaeological material. It is part of the Ilulissat Ice fjord World Heritage area and consists of a 3.5 metre thick layer of archaeological deposits rich in Greenland's history through the last 4,000 years. Most of these layers are constantly frozen, but the site is so low that the water reaches right up to it at high tide. This causes physical erosion of the layers, especially when salt from the high tide thaws the layers, so that they become less resistant than when frozen. Prognoses for the future climate of Qajaa indicate that the temperature will rise by 3-4°C by 2050, there will be more precipitation, and the sea level will rise by about 50cm. The raising of the land will be less certain – but hopefully more than 50cm. The effect this will have on preservation conditions is still uncertain. On one hand the rising temperatures will probably cause the site to thaw at some point, which could increase physical erosion and lead to some of the water draining away. On the other hand, the land may be lifted sufficiently that the physical erosion will be less and the increased precipitation might keep the layers saturated with water. The effects on conservation conditions are being investigated over three years from summer 2009 in a monitoring programme coordinated by the National Museum (http://nordligeverdener.natmus.dk/forsknings-initiativer/projektoversigt/klimaaendringer_og_koekkenmoed-dinger_naar_permafrosten_forsvinder/). The purpose is to assess

whether the site can and should be protected, or whether it should be excavated before it is too late. Problems with rising sea level, thawing permafrost and physical erosion of archaeological layers are far from unique to Qajaa, but affect many places in Greenland..



The site at Qajaa has archaeological deposits many metres thick, where the permafrost has ensured very good conservation conditions up until now.

(Photo: Henning Matthiesen)

parts of Scandinavia. Two complete arrows have been found in Jukkasjärvi in northern Sweden, for example.

The finds are mostly linked to reindeer hunting and mainly consist of arrows and arrow shafts. A number of sticks have also been found with loose wooden shavings or other items that could move in the wind tied to the top. These were set out in the snow to scare the reindeer and lead them in a certain direction during the hunt. A few wooden spades for burying the meat, a sword, a leather shoe and some fragments of textile have also been found. In areas where these objects are found, it is also common to find shooting positions behind which the bowmen hid themselves. The finds come from various periods and the oldest is C14-dated to around 4,000 years old. As well as being archaeological material of great scientific value, the finds are also a source of climatic history that can, for example, give an indication of the extent of the snow at different times. The items found consist mainly of organic material and when these are exposed to the open air they are vulnerable to rapid decomposition. They will therefore quickly disappear if they are not found and secured. Climate change, with its prognoses of rising temperatures, indicates that glaciers and snow patches will continue to melt and that many will disappear entirely. We may therefore expect a great many vulnerable archaeological artefacts to become exposed in the near future.

Less frozen ground in winter

Frozen ground in winter can also protect archaeological sites. In forested areas, archaeological material in the ground has been protected from destruction by heavy forestry machines

when the ground has been frozen in winter (Berghäll and Pesu, 2008). Milder, wetter winters where the ground does not freeze may lead to more damage and destruction of cultural heritage sites in forests, among other places.

2.4 Archaeological material under water

The spread of pileworm, acidification of the sea and increased erosion are possible effects of climate change that could affect archaeological sites in salt water. Increased erosion and higher temperatures may affect archaeological material in rivers and fresh water.

Underwater archaeological sites will probably also be affected by climate change, even though we do not currently know enough about how this will occur. If rising temperatures in the sea lead to the spread of pileworms, this will have a serious effect on wooden marine archaeological material. Acidification of the sea as a result of CO₂ emissions is another factor that can affect cultural heritage under water. Climate change may also influence waves and currents, leading to erosion and physical impact on shipwrecks, flooded dwelling sites and other subsea sites. Archaeological sites in and beside rivers and lakes could also be affected by flooding.

Changes in sea temperature and salinity

Climate change leads not only to a rise in air temperatures but also to the warming of the world's oceans (Hygen, 2008). This

will affect marine ecosystems, which may also have an effect on cultural heritage sites on the seabed. One example of this is the possibility that warmer water might provide better living conditions for pests such as pileworms, which may either extend their geographical areas or cause more pronounced effects where they are already found.

The pileworm or shipworm is a worm-like mollusc that lives on timber in salt water; it bores long tunnels into the timber that can damage or completely destroy structures. This family of molluscs includes many different species, only a few of which are found in Nordic waters. Pileworms are currently found along the coasts of Denmark, southern Sweden and Norway, Iceland and the Faroe Islands, but they have never been observed along the Finnish coast (Didžiulis, 2007). No self-reproducing populations have become established in Greenland either, although a few individual specimens have been found.

Pileworms represent a great threat to wooden archaeological material in all the locations where they have become established. The Baltic Sea is one of the few seas in the world that has been spared the damage caused by pileworms, since the salinity of the water is too low for it to live there. For this reason there are unusually many well-preserved shipwrecks in these waters. There are clear signs, however, that the pileworm *Teredo navalis* is slowly becoming established in southern parts of the Baltic Sea (WreckProtect, s.d.). The *WreckProtect* research project will be investigating whether this may be due to changes in the climate, for example in the form of higher water temperature and increased inflow of salt water from the North Sea. The project will gather data on environmental factors such as temperature, salinity, dissolved oxygen and currents and map this in GIS. The intention is to create a tool for assessing the potential spread of pileworms and subsequent decomposition of wooden archaeological items.

There is, however, disagreement about salinity trends in the Baltic Sea. According to the European Environmental Bureau (Det europeiske miljøbyrået, 2009), the salinity these waters has fallen steadily since the mid 1980s because of more rainfall and less inflow from the North Sea. Prognoses for the marine climate in the Baltic Sea suggest that this trend will continue. This should indicate that the climate changes would tend to make living conditions for pileworms in the Baltic Sea *worse*. The Technological Institute (Teknologisk Institut, 2010) in Denmark states several possible reasons for the spreading that are not climate-related, among others that the water in the Baltic Sea has become cleaner.

There is thus still a great deal of uncertainty about the cause of the spread of pileworms and what role climate change is playing. The results of the *WreckProtect* project are expected in 2011 and will hopefully help to improve our understanding of the spread of the pileworm and possible consequences for wooden archaeological material. Another question that remains to be answered is whether rising sea temperature could affect the spread northward of the pileworm, allowing some species to spread through the North Atlantic to Greenland and Svalbard, for example.

Acidification of the sea

Emissions of CO₂ into the atmosphere cause acidification of the sea, because large volumes of the gas are dissolved into the sea water as carbonic acid (Børsheim and Golmen, 2010). The mean pH value of seawater has been just over 8.0 for millions of years. Since industrialisation, the pH value has been reduced by 0.1. Prognoses indicate a further reduction of up to 0.5 in Norwegian and Arctic sea areas by the end of this century, a level that has probably not existed in the last 20 million years. Cold seawater can dissolve greater quantities of CO₂ than warm water, so there will be more acidification in Nordic waters, especially in polar and sub-polar regions, than further south. When the pH value goes down, the solubility of calcium increases. More acid seas will therefore lead to major ecological effects, mainly for molluscs, crustaceans and algae that form shells consisting mainly of calcium. In an archaeological context, acidification could represent a threat to flooded kitchen middens or shell heaps on the seabed (Blankholm, 2009). If the calcium content of such middens is broken down, the organic material that they protect will also be lost. Archaeological items with an alkaline content, such as bone and horn in calcareous gyttja in flooded dwelling sites, could also be negatively affected by an acidification of the sea.

Erosion of the seabed

Erosion is going on not only on land and on the coast, but also under water, where waves and currents move and remove seabed material. This contributes to the disintegration of shipwrecks and other subsea sites, and archaeological materials in areas with great storm and wave activity are most at risk. Prognoses for the future indicate that there will be a certain increase in storm activity, although there is some uncertainty about this (Hygen, 2008). Climate change could also bring about changes in ocean currents. This could affect subsea erosion and the movement of seabed materials and could cause greater mechanical stress on archaeological material. It is difficult to predict where and how this will occur, though, and how great an effect any changes in current and wave activity will have on underwater archaeological sites.

Changes in fresh water

A future increase in short, intense rainfall could cause more flooding in small drainage basins, as previously discussed in section 1.6. This means that the risk of flood will increase, especially in streams and small rivers in steep terrain. Generally speaking, there will be fewer snow-melt floods in spring in large parts of the Nordic region, while winter rain and flooding will increase. Floods in rivers and waterways can erode archaeological sites, of which there are often many along riverbanks (Blankholm, 2009). The deposit of silt carried by floodwater could also affect archaeological sites. Higher temperatures in water and marshland may also have a negative effect on conservation conditions for archaeological material.

3. Effects of climate change on cultural environments and landscapes

Climate change could lead to changes in cultural environments and landscapes as we know them. Rural landscapes are bearers of cultural history that is strongly linked to the primary industries. When these landscapes are changed, for example by the overgrowing of pasture land, the biological diversity of species in these cultural environments will be affected and the value of the experience will be changed. The extent to which climate change contributes to these processes is a subject of current discussion. Cities, towns and built-up areas also have their own characteristics that might make them particularly vulnerable to climate change.

3.1 Increased biological growth

A warmer climate will affect cultural environments and landscapes through an extended growing season, displacement of vegetation zones and changes in the diversity and composition of species.

Extended growing season

The report *Signs of Climate Change in Nordic Nature* (Nordic Council of Ministers, 2009) identifies a set of fourteen climate indicators that can be used to measure and evaluate climate change in Nordic nature. Two of these indicators apply to changes that are of great significance for landscape and cultural environments – an extended growing season and changes in the tree line.

According to this report, the growing season in southern parts of the Nordic region has become up to four weeks longer over the period 1982 to 1999. The figures are based on an interpretation of satellite images. The season has been most extended in Denmark, southern Sweden, south-west parts of Finland and coastal areas of southern Norway. However, the trend can be seen everywhere, apart from a few high altitude locations in the north where increased snow quantities have shortened the growing season somewhat. The length of the growing season can also be measured as the number of days with a mean temperature above 5°C (Hanssen-Bauer et al, 2009). In Norway such measurements show that during the period 1979 to 2008 the growing season has become from one to two weeks longer over most of the country, compared with the normal period 1961 to 1990.

The climate is an important prerequisite for plant growth and the length of the growing season has a significant effect on primary production. A continued rise in temperatures will extend the growing season even further and change the assumptions for the growth and extent of various types of vegetation in Nordic landscapes. A longer growing season also means that the season for the management of vegetation in cultural environments, in historic gardens and on

archaeological sites will be extended and that cultural environments that are not managed will become overgrown more rapidly.



Many cultural environments linked to pasture land and summer farms are becoming overgrown. Vibyggerå, Ångermanland.

(Photo: Bengt A. Lundberg © Swedish National Heritage Board)

Displacement of vegetation zones

Changes in the tree line and other vegetation zones are another effect of climate change that will be significant for cultural environments and landscapes. According to the Arctic Climate Impact Assessment (2005), the anticipated future rise in temperatures can be expected to lead to a displacement of the climate zones, in terms of both latitude and altitude. This will probably mean that the boreal coniferous belt will also move northward and upward, while birch forest will occupy more areas that are bare mountain today. In the Arctic the most important vegetation zones are the polar desert, with very little vegetation, the tundra with its stunted bushes and the northern coniferous forest. A warmer climate will probably lead to a displacement of the borderlines between these zones, so that the forest will encroach on the Arctic tundra and the tundra will extend into the polar desert.

The extent of vegetation and forest is not only dependent on climate, however, but also to a great deal on human activity. Mountain farms and pastures, tree felling in traditional forestry, mining and construction work have all had a significant effect on the development of the forest boundaries. In many places this has brought the tree line down to far below the climatic limit for the growth of trees. It is therefore important to distinguish between the climatic or potential tree line and the empirical or actual tree line. In the Nordic region, we can find examples of particularly marked cultural effects on forest growth in Iceland and Denmark. When Iceland began to be colonised about 1,100 years ago, large parts of the country were covered in birch forest. Centuries of exploitation caused the country to be almost deforested, as we know it

today. Unlike other Nordic countries, Denmark has no climatic limit for natural forest growth. At one time the country was covered with trees, but uncontrolled felling and clearance for agriculture reduced the forest to only 2-3% of the area of the country by about 1800. Since then, however, considerable forest areas have been re-established. Even in relatively thickly forested southern Norway, some 20% of the country is deforested (Bryn and Debella-Gilo, 2010), in addition to cities and built-up areas.

The climate puts limits on the geographical spread of different trees. While deciduous woods can only grow in southern parts of the Nordic region, birch forest is found in northern and higher altitude regions, right up to the point where climatic conditions permit no tree growth at all. In the borderlands between forest and bare mountain and in formerly open pastures and landscapes, overgrowing is currently taking place in the Scandinavian Peninsula and in Finland. In Iceland too, the mountain birch is reclaiming areas where sheep farming and pasture are in decline. How great an effect global warming has on overgrowing is uncertain. Studies of the effect of climate change on the displacement of tree lines in the Nordic region have arrived at different results (Bryn, 2008). While some find little evidence that the climatic limit for forest growth has changed, others believe they see that the climatic altitude limit for various types of tree has increased in recent decades. A number of recent studies have attempted to distinguish between the effect of a warmer climate and

the effect of less pasture and felling, to explain the ongoing overgrowing. The conclusion of a study of south east Norway (Bryn, 2008) is that the pushing out of the forest boundaries in recent decades has been mainly due to the reestablishment of forest where mountain farms have been abandoned. So far only insignificant areas of forest above the potential tree line for the normal period 1961 to 1999 have been established. It is none the less pointed out that this could indicate the beginnings of the effect of climate change.

Changes in the diversity and composition of species

Climate change could have consequences for both individual plant and animal species and whole ecosystems. New species can be expected to become established in areas where they were not previously found, while other species will move away or be displaced. As part of the *International Tundra Experiment*, a project during the International Polar Year, a meta-analysis was carried out of experiments on plant growth in tundra areas (Walker et al., 2006). The analysis was based on studies from Iceland, Svalbard, northern Sweden and the high mountains of southern Norway. The results show that changes in vegetation with higher temperatures occurred rapidly and could be observed after only two growing seasons. The height and coverage of bushes, scrub and grasses increased with a rise in temperature of 1–3°C. At the same time, moss and lichen coverage was reduced, as was the diversity of species.

Overgrowing at Þingvellir

Þingvellir has enormous historical and symbolic significance for the people of Iceland. It was here that the Icelandic Althing, a gathering of chieftains and representatives from the whole country, was formed in 930. The Althing continued to be held for two weeks every summer until the end of the 18th century. Iceland's first official court of law was also here, judging everything from land disputes to family feuds. Many archaeological traces from the time of the Althing can still be seen at Þingvellir, including the ruins of about fifty turf and stone storehouses. The remnants of the agricultural landscape of the 1800s can also be seen, as well as Þingvalla church and manor. Þingvellir with its cultural landscape is now on UNESCO's World Heritage list.

Climate change is expected to cause a mean temperature increase of 1°C in Iceland over the next 40 years. This will give longer summers, which could lead to increased plant growth and woods with higher and bigger trees. One of Þingvellir's most obvious characteristics is the natural mountain birch woods that grow in the area. Most of the vegetation is low growing, consisting of low birch trees, moss, heather and small bushes. If the temperature rises and the growing period becomes longer, new species of trees and plants can gain a foothold. Plant growth at Þingvellir has already increased, since the area is no longer used for grazing. Together with increased growth caused by rising temperatures, this could lead to great changes to the landscape. There is thus a great risk that the low cultural heritage

site of turf and stone could be overgrown and difficult to see and that the root systems of the new growth could damage the ruins.

The management of Þingvellir National Park has therefore devised guidelines for handling vegetation at the site. Species that do not belong to the natural flora of the location are being removed and trees and other growths that could damage archaeological traces or make them difficult to see are kept under control.



Both natural mountain birch and introduced spruce grow in Þingvellir National Park.

(Photo: Ville Miettinen. Licence: Creative Commons)

In landscapes characterised by long-term cultivation and pasturage, a rich biological diversity has arisen that is culture dependent. For example there is a rich diversity of grass and herb species in cultivated grasslands and pasture. Many plant species that are threatened in the Nordic region are to be found in these biotopes. Changes to these cultural environments are primarily due to new agricultural methods. However, climate change can accelerate change processes such as overgrowing, reduced diversity of species and the natural spread of new species (Framstad et al., 2006). A warmer climate will also probably bring the introduction of new, less hardy species in both agriculture and gardening.

Changes to grazing land

A warmer climate and an extended growing season will cause changes in grazing conditions for reindeer and other grazing animals. In northern Scandinavia and Finland there are large areas where the cultural environments and landscapes are characterised by reindeer herding. If climate change alters the grazing conditions for the reindeer, this will affect the very basis of reindeer herding, which represents a considerable part of the Sámi culture and identity. A report by the research institute Norut Alta (Lie et al., 2008) identifies several ecological effects of a milder climate that will have both positive and negative effects on reindeer herding. On the one hand, overgrowing of open moorland and a raising of the tree line will reduce the grazing area for the reindeer. Also, unstable winters with more frequent freeze-thaw cycles causing ice on the ground could make grazing poorer in the winter. On the other hand, a longer growing season will improve grazing. Areas near the sea with winter temperatures above freezing will also give better grazing if winter temperatures rise. These changes in grazing conditions could affect the areas of land used for reindeer herding. This could have consequences for cultural environments and landscapes associated with the Sámi communities that depend on reindeer herding.

3.2 Effects of extreme weather

More frequent episodes of extreme wind and rain, as well as long-term drought, will increase the risk of damage to cultural environments and landscapes. Urban landscapes may be particularly vulnerable to climate change due to their impermeable streets, inadequate storm drain systems and location beside water.

Extreme wind and rain

Extreme weather can do great damage to landscapes and cultural environments. When the storm Gudrun raged over southern Sweden in January 2005, it brought down a number of trees corresponding to a whole year's normal felling for the

whole country. Denmark was hit by the same storm, albeit to a lesser extent. As described earlier in section 2.1, the extent of storm damage to forest will probably increase in the future, especially in autumn and winter, as a result of climate change. Weather, water and wind are constantly eroding soil and rocks and causing a gradual change in the landscape. More extreme weather can lead to more acute change, in the form of storm damage or landslides. More flooding could affect buildings and infrastructure, as described in section 1.6, but also the landscape as a whole.

Urban landscape will be affected by climate change in several ways. Dense building and streets that are largely covered with asphalt, stone and concrete prevent rainwater from penetrating into the ground. Towns and cities are therefore especially vulnerable to extreme rainfall. In the urban landscape, surface water is handled with the aid of the sewer system and a future increase in extreme rainfall episodes will need a better storm drain system if water is not to cause damage. There has, however, been a positive trend in more recent town planning to recreate areas where natural drainage of rainwater can occur and to open up streams that have been channelled through pipes. This is now being done in many Nordic cities and helps not just to handle increased and more intense rainfall, but also to create a better urban environment.

The great majority of towns and cities are on the coast, and those that are inland are usually beside a river or large lake. A coastal location will make a number of towns and cities vulnerable to a rise in sea level and flood tides, while towns beside rivers may be at risk of flood. Urban landscapes and cultural environments that are both beside the sea and at the mouth of a river are particularly vulnerable, because a river flood may coincide with a flood tide and cause flooding from two sides.

Drought and fire

According to the UN climate report (IPCC, 2007), in a global context more periods of drought in future can lead to more forest fires. Drought and fire can affect both landscapes and cultural environments. Periods of drought not only increase the risk of forest fire but also the risk of fires in districts with historic wooden buildings. In the Nordic region, climate change will generally lead to more rainfall, but in some areas the summers will be drier (Hygen, 2008). This applies primarily to Denmark, south east Norway and the areas around and north of the Gulf of Bothnia. In these areas the risk of fire may increase in the future after periods of summer drought.

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Part 2

Consequences of climate change for the management of cultural heritage sites and cultural environments, and recommended action

4. Direct consequences of climate change for the cultural heritage sector

In the longer term, the effects of climate change can be expected to result in more damage to cultural heritage sites and increased losses. It will also be of significance for the management of cultural heritage sites that conservation conditions will change, whether for better or worse. Climate change may also lead to new finds of artefacts and sites. The consequences all this will have for the management of cultural heritage sites and cultural environments is the theme of section 4.1. Section 4.5 proposes some relevant action that can be taken to prevent loss and damage and to handle the changes that come.

4.1 More damage to cultural heritage sites

Prognoses for the future climate of the Nordic countries compared with historical climate data indicate that the impact of the climate on many cultural heritage sites is increasing. In the first part of the report, risks for increased decomposition and damage to various categories of cultural heritage sites were identified. Damage may partly be caused by an increase in decomposition over the course of time and partly be brought about acutely as a result of extreme weather incidents such as flood, landslide or tree fall during storms. Conclusively, if no action is taken, climate change will probably bring about an increase in the amount of damage to cultural heritage sites in the longer term.

Damage to cultural heritage sites is unfortunate for their management for many reasons. Repairing damage is resource demanding, and generally speaking preventing damage needs far fewer resources than repairing it. If a cultural heritage site is not repaired after damage has occurred, this is often the first step on the path to its destruction and loss. Repairing after damage has occurred is not without its problems either. The work normally involves replacing materials or making other alterations that reduce the cultural heritage site's authenticity.



Megalithic tomb overgrown with trees, before and after a storm.

(Photo: Torben Dehn © Heritage Agency of Denmark)

4.2 Increased loss of cultural heritage sites

More frequent extreme weather could increase the loss of cultural heritage sites in the future. Individual incidents of extreme weather may be due to natural variations in the climate, and such events do not show that climate change is occurring until they are included in statistical material that shows developments over a longer period. It can never be shown, therefore, that an individual site is lost because of climate change, even though it may be destroyed in a storm, a flood or a landslide. Even so, at an aggregate level, a warmer, wetter and stormier climate will probably lead to greater loss of cultural heritage sites.

Not just extreme weather, but also increased decomposition of cultural heritage sites over time could lead to increased loss of such sites. Climate change will mean an additional strain on a number of cultural heritage sites and could thereby lead to more of them being lost, without being in itself the primary cause. For example, heritage buildings that decay because they are not maintained and used will decay somewhat more quickly in a changed climate.

When cultural heritage sites are lost, we lose important items of value. Cultural heritage sites represent a source of knowledge, and from prehistoric times they are the only sources we have for understanding how people lived and worked. Cultural heritage sites can also provide a basis for attractions, increase living and environmental quality and be of significance for commercial development. Moreover, buildings represent an important resource for society. The loss of cultural heritage sites can therefore involve a loss for individuals, for a local community and for society as a whole. If a location is not recorded and documented, sites can disappear without our even realising what we have lost.

A number of cultural heritage sites will unavoidably be lost as a result of coastal erosion, melting snow patches or the



thawing of the permafrost that protects them. In the longer term, the rising sea levels will also cause losses of coastal cultural heritage sites in vulnerable areas. It will be impossible to conserve all these cultural heritage sites. The resources that would then have to be engaged would be disproportionately large. It is therefore not just a point to prevent losses occurring, but to make priorities regarding which cultural heritage sites we should use resources to save. This demands good tools in the form of systematic knowledge and clear principles and criteria for prioritising.

4.3 Changing conservation conditions for cultural heritage sites

Climate change will mean that conservation conditions for various kinds of cultural heritage sites could change for the better in some places and for the worse in others. While in general a damper climate will lead to deteriorating conditions for heritage buildings, the effect on conservation conditions for archaeological sites is less certain. In some places conservation conditions for archaeological material under ground could also improve because the water content of the earth becomes higher. In other places, conservation conditions will become worse because of increased erosion or – in Arctic regions – the thawing of permafrost in the earth in which archaeological material lies protected.

Today we do not know enough about how climate change will affect conservation conditions for cultural heritage sites, particularly archaeological material in earth and water. Such knowledge is decisive for the proper management of the sites. Changes in conservation conditions, whether for better or worse, could lead to our having to reassess the management of cultural heritage sites and the use of resources.

4.4 New finds of artefacts and sites

The melting of snow patches has already led to a number of new finds of archaeological material. With the melting of snow increasing in the future, more artefacts will be revealed. In a similar way, erosion can in some cases reveal previously unknown archaeological sites. Sites that are in danger of being lost to erosion or other climate-related events can also lead to more archaeological excavations and thereby new finds.

New finds of cultural heritage sites will give us new knowledge about the past. At the same time, a greater extent of such sites will increase the pressure on responsible authorities and institutions. Storage, research and disseminating information all demand resources. Even if it is decided to take care of only a small part of the material found, documentation and the required assessments and prioritising will still require resources.

4.5 Recommended measures

As we have seen, climate change will have consequences for cultural heritage sites and cultural environments and for their management. In this section, various measures are recommended that can be taken to handle these consequences. There are some good opportunities to prevent and hinder climate-related damage and loss.

Besides the suggested measure, there are also some current examples from various parts of the Nordic region. The examples show measures that have already been taken or are currently being implemented, and that will help to prevent climate-related damage to cultural heritage sites. Some of the examples also show how existing measures can be further developed so as to meet the climate challenge.

Identification, mapping and documentation of cultural heritage sites that are particularly vulnerable to damage as a result of climate change

The identification, mapping and documentation of vulnerable cultural heritage sites is a basic prerequisite for implementing measures that can hinder damage and loss. The project of which this report is a part has identified various categories of cultural heritage sites and cultural environments in different areas of the Nordic region that will be affected by climate change. Such work can be done in much more detail for each individual country or for special geographical or administrative areas. Mapping should be done to the extent and with the degree of detail that is appropriate for a specific use in the management of cultural heritage sites. With limited resources, it will be natural to prioritise areas with a high risk of climate effects and with many cultural heritage sites or with sites of special value. How detailed the documentation should be must also be weighed up against the value of documenting all of the threatened locations or as many as possible. It is especially important to arrange good documentation for those cultural heritage sites that will inevitably disappear.

The further development of cultural heritage databases and digital maps will help to provide useful tools for mapping vulnerable cultural heritage sites. In all the Nordic countries, cultural heritage databases based on GIS (Geographical Information Systems) are either in use or are being prepared for use, as in the Faeroe Islands and Iceland. Most of the countries also have some form or another of searchable, map-referenced cultural heritage data for the public on the internet, or are in the process of getting it. The most populous Nordic countries have come furthest in this work because of the access to greater resources, but the smaller countries are also following behind.

GIS-based databases should be further developed, both technically and in content, so as to get the best possible map solutions into use in public cultural heritage management and land use planning. Climate-related information could also be integrated into these systems. Vulnerability assessments could be included, for example, with climate-related vulnerability as one of the parameters.

Cultural heritage data can also be combined with datasets from other sectors, so as to give maps with integrated information about climate-related threats. For example, flood zone maps can be combined with cultural heritage data, so as to map out cultural heritage sites that are vulnerable to flood risk. Such a mapping of sites of national interest that are vulnerable to flooding is done in Finland, among other places.

In Denmark, cultural heritage sites are included in flood scenarios in collaboration with the Danish Coastal Authority. In a similar way, geographical maps that show landslide danger as a result of climate change can be combined with geographical data on archaeological sites and historic buildings. If this is to provide results that could give clues about the risk to specific sites from landslide or flooding, the map must however have a high level of detail. Such mapping could be an important tool in public cultural heritage management in the future.

Repairing climate-induced damages to cultural heritage sites

Cultural heritage sites that have been damaged as a result of climate-related events should as far as possible be repaired. Damage that is not repaired often leads to further decay. The extent of the damage and an assessment of the value of the cultural heritage site will, however, form a basis for whether repair is the right action. Repairing and restoring cultural heritage sites demands trained people and the right expertise, for example in traditional building practice and handwork. Work on heritage buildings depends on access to the right materials of good quality. In certain cases it can be relevant to restore not only buildings but also archaeological sites, for example when ruins or prehistoric tombs have suffered storm damage.

Intensification of exterior maintenance of heritage buildings

By and large it is poorly-maintained buildings that will most quickly be damaged in a warmer, damper, and more stormy climate. In order to prevent damage to heritage buildings as a result of climate change, more frequent inspection and more intensive exterior maintenance will be important measures. The maintenance must also be done correctly. Paint and plaster to be used on old buildings should be porous, so that damp that enters the walls can escape. It will be even more important than it is today to lead water away from buildings effectively and that the drainage has enough capacity to handle extreme weather.

The Swedish National Board of Housing, Building and Planning (Boverket, 2007) has published the report *Byggnader i förändrat klimat: Bebyggelsens sårbarhet för klimatförändringars och extrema väders påverkan* (Buildings in a changed climate: the vulnerability of buildings to the effects of climate change and extreme weather) as part of a government project on climate and vulnerability. Among other things, the report discusses the economic consequences of climate change. Estimates were made of cost increases

to society of things like shorter intervals between painting wooden facades and windows and a shorter lifetime for plaster facades. Just as for other buildings, we must assume that the cost of maintenance of heritage buildings will increase in the future because of climate change.

Documentation and maintenance plans will be useful tools for preventive maintenance. On the basis of this documentation and of earlier work, plans can be made for future maintenance that allow for increased climate impact. The use of maintenance plans in managing heritage buildings is not very widespread as yet in the Nordic countries, however. In most Nordic countries, it appears that management, operating and maintenance plans are mainly used for state-owned heritage buildings. It would also be beneficial to use such plans for other protected and heritage buildings, and following the plans would help to prevent climate-related damage.



The need for maintenance and repair will increase as a result of climate change.

(Photo: Kjell Andresen © Directorate for Cultural Heritage, Norway)

Intensification of vegetation management on cultural heritage sites

A warmer climate will lead to an extended growing season and increased biological growth in the Nordic countries. This will increase the overgrowth of ruins and other archaeological heritage sites. More intensive management of vegetation is a measure that will help to keep cultural heritage sites free of growth that can cause decomposition and damage from roots. Management plans will therefore be an important tool for this work. When cultural heritage sites are visible and not hidden by vegetation, they are also less likely to be damaged by forestry and construction work.

Climate change can also cause more trees to be brought down by wind and have their roots tipped over, which can cause damage and destruction to heritage sites. The most important preventive measure against this type of damage will be to keep cultural heritage sites free of trees. On larger heritage sites one should ensure that the entire locality is cleared at the same time.

On buildings too, increased biological growth will mean that vegetation growing over or near heritage buildings must be cleared more frequently. Trees beside a building create a damp microclimate and shut out sunlight, so that the damp takes longer to dry out. Wet leaves and pine needles on roofs and in gutters can also easily lead to damp-related damage.

For historic gardens and other green areas, a longer, warmer growing season will increase the need for management. A warmer climate will of course help less hardy plant species to survive, but will also require a more intensive combating of new and damaging species that will become established in the Nordic countries.

Increased overgrowth of cultural environments and landscapes and the raising of the tree line in the Nordic countries are primarily due to changes in agriculture, with less use of open pasture for grazing and harvesting. Climate change will only accelerate overgrowth of cultural heritage sites and the raising of the tree line. If measures are to be implemented to restrict vegetation over wide areas, collaboration with the agricultural sector will be a possibility.

Measures to improve conservation conditions for archaeological material in the ground

In some cases it may be advisable to implement measures for improving conservation conditions for archaeological heritage items in the ground. This may involve various kinds of measures, such as preventing the erosion of heritage sites or securing the water content of earth that contains layers of archaeological deposits.

In the expectation of more wind and more frequent periods of heavy rain in the Nordic countries, the problem of soil erosion will probably increase. Establishing soil cover and reseed-ing erosion-prone areas could have positive effects for heritage sites that are in danger of eroding away. In Iceland soil erosion is one of the biggest environmental problems, due to thin soil, wind and overgrazing. The country's cultural heritage and soil protection authorities are working together to sow grass at Þjórsárdal, where erosion has been extensive. Measures like this help to prevent the erosion that is threatening the heritage site.

Water erosion can also threaten archaeological sites. In special cases, rerouting a waterway may be the best way of preventing the loss of heritage sites to erosion. The text boxes present two other examples of how cultural heritage sites can be secured and show the range from large, costly projects to small-scale local measures.

Re-establishing wetlands

In Denmark, the government's *Grøn Vækst* (Green Growth) plan intends to spend a billion Danish kroner on re-establishing wetlands. The purpose is primarily to improve water quality and reduce nitrogen and phosphorus runoff from agricultural land. However, re-establishing wetlands also has a positive effect in terms of adapting to the climate, because such areas will act as buffer zones when there is extreme weather. Although not the real purpose of the project, re-establishing former wetlands will have a positive effect on conservation conditions for archaeological material in the ground. And these old, dried up lakes and wetlands contain a great many sites of heritage interest. In these places, people, animals, spoils of war, food and metals have been sacrificed or hidden away in prehistoric times. By making these areas wet once again, hopefully much of this will be preserved, including the organic materials. There is a potential problem, however, in that the construction work necessary to re-establish the wetlands may cause damage to the heritage sites. And in many cases no funding has been made available for archaeological surveys before work begins. It is therefore very important to ensure that contractors and site workers are informed about the archaeological heritage that lies within the ground.

Local action on frozen midden

A partial excavation of a frozen kitchen midden from the Saqqaq-culture on the island of Qeqertasussuk in Sydostbugten in Greenland was concluded in the late 1980s. In the excavated area, a wall of wood was put up against the edges in an attempt to keep the remaining layers of earth moist and thereby also frozen. In 2009 it could be confirmed that this simple structure had retained the permafrost in the part of the midden that lay against the wood. It is believed this has been possible because of a number of local conditions. This is an example that shows that measures to prevent climate-related damage to heritage sites can also consist of simple, local solutions and that it is certainly worth trying out different methods.

Archaeological excavations and documentation

Excavation of archaeological sites because of natural damage and erosion may become more relevant in the future as a result of climate change. There will also probably be more excavations in connection with developing renewable energy and new infrastructure relating to climate change. In both cases, it will be important to document the cultural heritage sites and the context in which they are found, before they are lost.

In the case of developments, the excavations will usually be financed by the developer. In the case of natural damage and erosion, finance must usually come from the cultural heritage authorities' budgets. In Denmark, erosion is a factor that is incorporated into the Museums Act, so that certain funding

can be given to archaeological excavations in erosion-threatened areas both on land and under water. There are also other examples of models for financing archaeological excavations in threatened locations. In the Faroe Islands, surveys were made of the eroding cliffs at Junkarinsfløttur and á Sondum in the settlement of Sandur at Sandoy between 2003 and 2007. This project was financed jointly by oil companies and the Faroese research fund.



Archaeological excavation of the eroding cliffs in Sandoy, Faroe Islands.

(Photo: Símun V. Arge, National Museum of the Faroe Islands)

Coastal defence measures

Sea level rise and coastal erosion in the exposed areas threaten not only cultural heritage sites, but also buildings and infrastructure in general. While coastal erosion is already a known problem in many parts of the Nordic region, rising sea levels could also create an even bigger challenge in the future. Protecting cultural environments in cities and populated areas affected by sea level rise will increasingly become a societal concern rather than a matter of the management of an individual heritage site.

However, small-scale coastal defence work will be important for protecting certain, particularly important heritage sites from erosion and rising sea levels. Several different measures may be relevant. For example, breakwaters in the form of large stones can be placed in the sea in front of the heritage site, dams and dykes of different kinds can be built or the water's edge can be protected with sandbags. Research is continuous into new ways of securing coastal zones against erosion, since this is a considerable problem in large areas.

These measures should not involve too great an impact on a cultural environment, so that the physical protection disfigures or damages the heritage site. At the same time, the coastal defences must be strong enough to withstand the forces of waves and storms and of the breakup of ice in the spring in areas where the sea freezes. There are many examples of attempts to protect heritage sites with measures like depositing stones in the sea, where the protection has been broken down by the sea fairly quickly.

Coastal protection for cultural heritage sites

In Kirkjubøur, the Faroese bishopric of the Middle Ages, the medieval parish church has been protected from the sea by a wall since 1874. This was erected to protect the church after the sea had repeatedly invaded the churchyard. It is uncertain whether the wall will hold if exposed to greater strains than at present. A large part of a smaller church building in the area, Líkhús, has already been lost to the sea. A protective wall to secure the rest of this church was erected in the 1940s by the local farmer. This worked as intended until it was damaged in a storm in January 2008. Repairs were funded by the heritage authority Føroya Fornminnisav. Kirkjubøur is only one of many archaeological sites on the Faroe Islands that are threatened by coastal erosion. It has not yet been determined which agency or authority in the Faroe Islands is responsible for handling the problems caused by coastal erosion and rising sea levels, and this presents a problem for the cultural heritage authority.

Instead of protecting heritage sites from the sea where they are, another option in some cases is to move them. This has for example been done with trappers' cabins in Svalbard. Such cabins are small, simple buildings that can easily be moved further inland. In Denmark, the medieval stone church Mårup Kirke in northwestern Jutland has also been taken down because it was threatened by coastal erosion. While it was being dismantled, the archaeology and building techniques were documented, but as yet there are no plans to re-erect the church on another site. Moving a building necessarily means losing the original environment to which it belonged. However, there is a difference between moving the building to a completely new context and moving it a little further inland.

In special cases, archaeological sites can be moved as well as buildings. At Tryggelev Nord at Langeland in Denmark, a late Stone Age megalithic tomb that was in danger of falling into the sea was moved further inland. The archaeological context is nevertheless unavoidably lost with such a move and must be documented. This loss is so significant that moving archaeological heritage objects is seldom justifiable. Whatever the case, if a site or object of cultural heritage interest is moved, information must always be provided about why it was moved and what has been lost.

Monitoring

The systematic monitoring of selected cultural heritage sites and cultural environments is important, so as to be able to track the quantitative and qualitative changes that occur. Monitoring may be done locally for a specific site, for example with the aid of photography and measurements. In the public management of cultural heritage, however, monitoring is normally taken to mean programmes for the systematic monitoring of a representative selection of heritage sites. The most widespread method is still field work, i.e. visiting a known

heritage site to check whether it is intact, damaged or lost. The reason for any damage or loss is recorded at the same time. The situation is documented by means of photographs and the location is determined digitally, if this has not yet been done.



Installing equipment for local monitoring of soil temperature, thawing, and the water content of frozen layers of archaeological deposits. Qajaa, Greenland.

(Photo: Henning Matthiesen, National Museum, Denmark)

Local monitoring of a 4,000-year-old midden

An example of local monitoring of a specific site is that of a Stone Age midden at Qajaa, in Jacobshavn Isfjord. In 2009, Greenland's National Museum, in collaboration with the National Museum in Denmark, established a measuring station on this site. The station will gather data about conservation conditions in the three-metre-deep midden. The site will be equipped with cameras for year round photographic documentation of snow conditions, i.e. precipitation volume, where the snow lies and how melting proceeds.

In recent years, high-tech tools and non-destructive methods such as satellite monitoring, LIDAR (LIght Detection And Ranging), georadar and magnetometers have come into use for monitoring purposes. These methods also make it possible to discover previously unknown heritage sites, such as those that are no longer visible above ground level. The different monitoring tools can be used as needed. While satellite data give a good picture of a large geographical area, georadar or magnetometers can be used to go into greater detail. In most cases verification will still be necessary using field work, but this can be made more targeted and effective.

The technology in this area is developing all the time and will provide new opportunities in the future. Where monitoring programmes continue over many years, the results can give

an insight into slow changes such as those typically caused by climatic effects. Monitoring therefore has the potential to be a good control tool for national heritage management in tracking climate-related damage to heritage sites in the future. Developing and introducing relevant and quantifiable indicators is a challenging task, however.

National monitoring programmes

The Directorate for Cultural Heritage in Norway has monitoring programmes for a number of protected archaeological sites and heritage buildings. The first monitoring checks on automatically protected archaeological sites were carried out in 1997, and in 2001 16 local municipalities were selected on the basis of criteria such as geographical location, local industry, types of heritage sites and whether the local population was increasing or decreasing. Four municipalities are checked each year, so that each is checked every four years. The monitoring programme for buildings is organised in the same way. The registration methods have been standardised (NS 9450), so as to guarantee comparability in the results. Types of land use, any damage or loss and the causes of damage or loss are all recorded. The records of causes of damage to archaeological sites show an increase in damage caused by windfall and erosion. At present there is not a sufficient basis to say whether this increase in damage is climate-related or not. If data about the condition of heritage sites can eventually be linked to information about the climate, however, we will have the opportunity to look for climate-related connections over the course of time.

Advice to owners and administrators

Cultural heritage authorities should give advice to owners and administrators of cultural heritage about how to take care of buildings and sites in a changing climate. Advice about preventive maintenance and adaptation to climate change will be a key. This can be achieved through existing information channels, including websites, information sheets, guidelines, handbooks and personal contact.

Dedicated fora can also be established, although this will be more demanding of resources. In England for example, English Heritage has set up the website www.climatechange-andyourhome.org.uk. This includes a service in which you can enter where you live and what kind of building you live in. On this basis, information is given about the possible effects of climate change on that building, as well as recommended energy-saving measures.

Developing knowledge and expertise

Knowledge of and expertise in heritage management is vital for understanding how climate change will affect heritage sites and how potential damage and loss can be prevented. Building up knowledge and expertise must occur in several areas.

Craftsmen must have knowledge of how to use traditional techniques and materials in order to be able to repair and maintain heritage buildings and prevent climate-related damage. This entails a need for further education and training for craftsmen in restoration and traditional building practices.

Research can help to develop knowledge about climate effects on cultural heritage. Even though research is being done into both the exterior and interior climate and the conservation of cultural heritage, little work has been aimed directly at cultural heritage and climate change. There is therefore a need for more knowledge about how changes in the climate affect heritage sites and cultural environments, at both micro and macro levels. Climate change is a complex phenomenon that will increase the need for cross-sector research. There are many different research centres with expertise that is relevant for climate effects on cultural environments. They may be anything from meteorological research centres to those researching into building materials or paint products.

There is also a need for research into how knowledge inherent in cultural heritage and traditional solutions can contribute to solve future challenges resulting from climate change.

The Nordic countries face many of the same challenges relating to taking care of cultural heritage sites in a changing climate. The exposure of buildings to increasing damp, for example, will be a challenge common to the whole Nordic region, and the Arctic areas will face many of the same problems, for example from thawing permafrost. Since the Nordic countries are relatively small, research projects across national borders and the exchange of research results and experiences will be especially important for acquiring the necessary knowledge about climate change and cultural heritage sites.

Response planning that takes climate change into account

Emergency response plans for securing cultural heritage sites must take into account the risks associated with climate change. This applies particularly to what extremes one must be prepared to deal with in regard to future extreme weather. Heritage sites must also be brought into response plans and plans for climate adaptation in other sectors.

Mapping flood risk

The purpose of the EU Flood Directive is to handle the risk flooding represents to people, the environment, cultural heritage and the economy, with a view to reducing flood damage. The directive covers all kinds of flooding, including that caused by flood tides from the sea. The directive sets out requirements for risk assessment and total planning of damage-preventing measures for each drainage basin. In Sweden, the Swedish National Heritage Board is involved in a nationwide mapping of which areas have a significant risk of flooding. This takes into account both the probability of flooding and the possible consequences in the form of damage. The National Heritage Board's contribution is an assessment of the effects on cultural heritage sites.

Evaluation of public heritage management principles

In some areas it is possible that climate change will have such a marked effect that the existing management principles must be evaluated. This may be the case, for example, if rising sea levels threaten a significant number of cultural heritage sites. If future climate change puts many heritage sites under pressure, a reassessment will be needed of which sites one should use resources on protecting.

It will be important to have the right criteria and other tools in order to be able to prioritise. The assessment of value is a key element of such processes. Heritage sites may have both different values and different types of value, and it may be that the assessment of these values must change.

It is also possible that other principles of public heritage management must be reassessed in the longer term as a consequence of climate change. This may affect both the distribution of responsibilities and the distribution of resources. This must be done in each country, so that each country's public heritage management has an organisation and the resources to match the tasks it has been assigned to solve.

4.6 Conclusion

Climate change will represent an additional strain on many cultural heritage sites. Even though it may be difficult to demonstrate that any one instance of damage has arisen because of climate change, the amount of damage and loss as a whole will probably increase.

Even so, it will to a large extent be possible to prevent climate-related damage. For buildings, most climate-related damage may be prevented by means of more frequent inspection and exterior maintenance. Climate-related damages to archaeological sites will be more difficult to prevent, not least because of their sheer extent. For selected archaeological sites, it will be possible to prevent climate-related damage with the aid of increased vegetation management, coastal defence measures and other relevant action. Systematic monitoring over an extended period could also be an important tool for keeping track of the effects of climate change on cultural heritage sites.

In parts of the Nordic region, coastal erosion and, in the longer term, rising sea levels will demand a re-assessment of which heritage sites one should use resources on saving. In those cases where the loss of heritage sites cannot be avoided, or can only be avoided by the use of disproportionate resources, documentation will be all the more important.

5 Consequences for the cultural heritage sector of climate-related changes in other sectors

Cultural heritage sites and cultural environments are already being affected by society's response to climate change. International agreements and national targets for cuts in greenhouse gas emissions rely on a number of measures being implemented. The question of the production and consumption of energy is central to this. The instruments used by the authorities to implement emissions-reducing measures are partly legal, partly economic and partly based on providing information. Both the development of renewable energy sources and energy efficiency are measures that will affect archaeological heritage sites, heritage buildings and landscapes in different ways.

Different sectors are also working on measures to adapt to the climate change that in all probability will come. This work is partly aimed at handling increased rainfall. Such measures could also affect heritage sites and our management of them.

5.1 Energy efficiency

Energy efficiency is a vital tool in limiting greenhouse gas emissions and thereby mitigating climate change. A reduction in the use of fossil energy like oil, coal and gas reduces emissions directly. In many of the Nordic countries, however, electricity based on hydropower is used for heating buildings. This is a form of energy production that does not in itself cause greenhouse gas emissions, and the same applies to wind power.

Even though not all energy sources cause greenhouse gas emissions, energy saving is considered to be an important climate measure. The reason for this is that power from clean and renewable energy sources should be released for purposes other than heating – for example for recharging electric cars. In this way society can use less fossil energy and reduce greenhouse gas emissions overall. As part of cross-border energy trading, the export of clean energy can also replace energy from coal fired power stations and other energy sources that cause large CO₂ emissions. In addition to the climate arguments, there are also economic arguments for energy efficiency. Energy saving measures that reduce costs for heating will be attractive to all householders.

There are, however, differences between the Nordic countries when it comes to how focused they are on energy saving in buildings generally, and thereby also buildings of heritage value. Iceland has a great deal of energy available; more than 80 per cent of houses are heated geothermically. There is less of a focus here on energy saving than there is, for example, in Denmark, which does not have the same natural energy sources.

Energy saving measures in heritage buildings

Saving energy and resources is nothing new, but is something that has always been important in construction, as resources

have been limited. But older buildings are based on the conditions of their own times, and today they are less energy efficient in operation than most modern buildings. For this reason, energy saving measures in old buildings of heritage value will be especially important for reducing energy consumption.

Heritage buildings that are legally protected are unlikely to be at risk of exposure to unfortunate energy saving measures. The same applies to buildings that are not necessarily protected by law, but are nevertheless subject to strict conservation practice, for example museum buildings. The number of protected buildings and museum buildings is modest, however, in relation to the large number of buildings that have a certain heritage value but are not subject to legal protection or listing. Buildings with a heritage value that is not clearly defined can easily be subjected to energy efficiency measures that reduce their heritage value. It is among all these buildings, therefore, that we will find the biggest problems with energy saving.

Energy saving measures that are carried out without sufficient professional expertise may lead to damage to buildings. If weather sealing and insulation of old buildings is done incorrectly, it can result in damage caused by damp. There may also be problems with the air quality inside old buildings as a result of excessive weather sealing.

Energy saving measures should also make sense economically. Investments in such measures will be less worthwhile in buildings that are only used occasionally than in buildings that are used all year. In some cases measures can be made more expensive because the building is protected or worthy of preservation, due to the extra cost of surveys, documentation and other items.

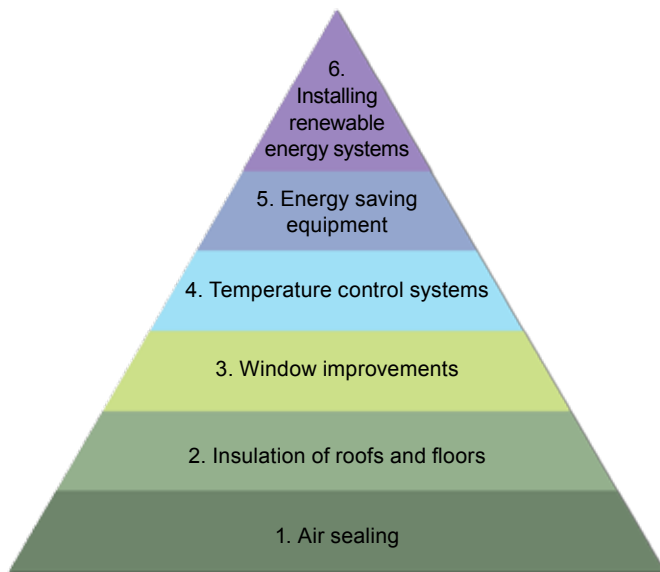
It is however entirely possible to save energy in heritage buildings while also taking their heritage value into account. How intrusive energy saving can be allowed to be must be weighed up in every case against any loss in heritage value or authenticity. The greater the heritage value a building has, the smaller the intrusion on it should be.

One simple, but effective energy saving measure for heritage buildings is sealing around windows, doors and other places with air leakage.

Insulation of roofs and floors will often be a good solution, while insulation of walls should be avoided. Windows are an important part of a facade and of a building's identity and they should therefore be repaired and improved, rather than replaced. Installing double glazing or low emission glazing in the existing secondary window is a recommended solution for obtaining good insulation. Adding a secondary window can even provide better insulation than replacing the old one with modern double glazing.

Energy management systems are also a good way of saving energy in heritage buildings, and there are simple and inexpensive systems for temperature control and reducing consumption

at night. In larger properties, more advanced energy management systems can be used to reduce energy consumption.



Recommended sequence from 1 to 6 for carrying out energy saving measures in heritage buildings.

(Illustration: Fiin gammel aargang, Sintef 2004)

Temperature control in churches

The permanent heating of churches, which became normal in many parts of the Nordic region from the mid-20th century, led to problems with damage caused by the buildings and interiors drying out. Several surveys have shown that temperature control gives better conservation conditions for church buildings and interiors. Temperature control systems heat the church up quickly when it is in use and otherwise keep it at a lower temperature. With the aid of simple control systems, one can both save energy and improve conservation conditions for heritage buildings.

Even though many things must be taken into account in relation to energy saving in heritage buildings, it is in the interests of the owners, cultural heritage authorities and society that energy saving measures are carried out. This will reduce heating bills and improve comfort, thus helping to ensure that the buildings are both maintained and used.

Renewable energy systems in heritage buildings

Changing energy source from fossil or electricity to other energy sources is another way of reducing greenhouse gas emissions and energy consumption. Such a change in energy source may compensate for an older building's greater energy needs compared with a new building, while simultaneously reducing heating costs.

There are various alternative energy sources that intrude to various degrees on a building during installation. Many alternative energy sources rely on a water circulation system for carrying heat around the building. This is the case both

for geothermal heating and for connection to district heating. Installing a system that relies on water circulation involves a fairly large impact on a building's interior, and a decision must be made whether this is acceptable in a heritage building.

The installation of air-to-air heat pumps is simple in existing buildings, and the physical impact on the building is small. The exterior part may, however, have a detrimental effect on the facade and it can be difficult to find a discreet spot to place it. The same applies to solar heating systems and solar panels.



Air-to-air heat pumps have little physical impact on the building, but it can be difficult to find a discreet location.

(Photo: Anne Kaslegard, Directorate for Cultural Heritage, Norway)

Wood and bio-pellets are other eco-friendly energy sources that do not have a negative effect on CO₂ accounting, even though burning wood emits particles into the immediate environment. Wood- or pellet-burning stoves normally have no greater physical impact on a building than connection to a chimney and can certainly be used in heritage buildings. If a building has old stoves that are worth conserving, then naturally these should not be replaced.

There is no simple answer to what energy saving solutions are best for protected and heritage buildings. Solutions must be assessed on conditions for every individual building. The local climate will also affect which measures are chosen. Adding insulation, for example, gives most benefit in areas with cold winters, while air-to-air heat pumps are at their most efficient when the outside temperature is not too low.

The use of instruments to achieve energy efficiency

The authorities use various instruments to achieve energy efficiency effects. Tightening up building regulations, energy labelling of buildings and economic instruments in the form of grants and duties also affect the management of heritage buildings.

Generally speaking, there has been a gradual tightening of energy requirements in building regulations in all the Nordic countries. Currently the energy requirements are mainly for new buildings and major rebuilds, but the requirements may increasingly come to bear on renovation of existing buildings.

From the point of view of public heritage management, it is desirable to put forward alternative measures in the regulations for cultural heritage buildings. This applies to both energy saving measures that can be implemented without losing heritage value and the use of renewable energy sources especially for this type of building.

The intention of the EU Directive on the Energy Performance of Buildings (2002/91 EC) is to help reduce energy consumption in buildings. The directive has been adopted by the EEA Committee and has therefore also been adopted in Norway, but not at present in Iceland. Greenland and the Faeroe Islands, which are not members of the EU, do not follow this directive.

The directive gives a common framework for promoting more energy efficient buildings in the EU/EEA and states a common method for calculating a building's energy consumption. It also defines energy requirements for new buildings and buildings that are renovated, with certain exceptions. The directive introduces requirements for energy labelling of new and existing buildings that are intended to show how energy efficient a building is. In the energy certificate, a building is marked from A to G, A being the best. The idea of giving buildings an energy labelling is that low-energy buildings will be more attractive to buy or rent.

In all the Nordic countries in which energy labelling has been introduced, a number of exemptions from the scheme have been made for various groups of heritage buildings. These exemptions show that there is currently some uncertainty about how such buildings should be handled in terms of energy questions. Even though energy labelling is not required for many heritage buildings, it should be an overall goal that such buildings should not use more energy than necessary.

Protected half-timbered house with a B energy label

Bremerstente is an agricultural worker's house dating from 1820, located in the grounds of Brahetrolleborg Manor in southern Funen in Denmark. In 2005, the Heritage Agency of Denmark bought the house, which was in very poor condition after standing empty for many years. The purpose of buying the house was to turn it into a modern and energy efficient home. As much as possible of the house's original materials and details was kept, and appropriate energy saving measures were carried out. The house was also equipped with heating from a ground source heating system buried in the garden. When the work was finished, the house received a B label in the energy labelling scheme. This is a good example of how energy savings can be made in heritage buildings without losing heritage value.

The authorities also use economic instruments to promote energy saving. On one hand, the use of charges on CO₂ and electricity can help to promote energy saving. On the other hand, the authorities have support schemes in the form of grants for energy saving measures and changing to alternative energy sources. Such

schemes are found to a greater or lesser extent in all the Nordic countries and contribute to more energy saving measures being implemented. This can lead to pressure on older buildings, with investments being made in unsuitable measures that reduce the heritage value. At the same time, many of the solutions that receive support can certainly be used on heritage buildings, provided one is aware of the need to respect heritage values.

Nordic websites and publications that give advice about energy saving in heritage buildings:

Bygg og bevar:

<http://www.byggogbevar.no/enock-i-eldre-bygninger.aspx>

Bygningskultur Danmark:

http://www.bygningskultur.dk/Materiale/User+Upload+Files/Vidensbase+filer/energiguide_light_FINAL.pdf

Sintef (2004): Fiin gammel årgang. Energisparing i verneverdige hus.

http://www.sintef.no/static/bm/fiin_gammel_aargang.pdf

Slots- og Ejendomsstyrelsen:

<http://www.ses.dk/da/Energi/Energioptimering%20af%20fredete%20ejendomme.aspx>

Spara och bevara:

<http://www.sparaochbevara.se/index.php>

5.2 Developing new energy sources

Climate change calls for readjustments in the energy sector. The transition from fossil fuel to renewable energy sources is a key element of energy policy, and the production of renewable energy must therefore increase in the years to come. The Nordic countries have great potential for producing such energy, especially wind power, hydropower and bioenergy. However, the exploitation of wind and water power requires major developments that will affect both the landscape and archaeological sites. The consequences of changing over to the production of bioenergy are discussed in section 5.3, in the context of changes in agriculture and forestry.

Wind power

Windmills require a wide area and are highly visible elements that will effect cultural environments and landscapes. The development of wind power that will take place over the next few years will therefore require detailed assessment of possible locations, including with the aid of landscape analysis.

Denmark is the Nordic country where the development of wind power has come furthest. Over 20% of the electricity in the country is produced by windmills, and development continues. Wind power is a renewable energy source that is also being increasingly developed in Sweden, Norway and Finland. Greenland's first windmill recently came onstream, and the potential for a larger development of wind power is

being investigated with the aid of wind-measuring masts. On the Faeroe Islands there are also a couple of wind farms and plans for further development. In all the countries there are public support schemes for the development of wind power as a source of electricity.

Several of the Nordic countries' cultural heritage administrators are working on wind power and landscapes. In Norway, the Directorate for Cultural Heritage (Riksantikvaren, 2010) recently published the report *Visualisering av samverknader på landskap av vindkraftutbygging* (Visualising the total effects on the landscape of wind power development). This discusses various visualisation methods that can be used to show the effects a wind farm will have on the landscape. The Directorate for Cultural Heritage has also created a summary of areas in which there will be great conflicts of interest between the establishment of large, land-based wind farms and the preservation of landscapes, cultural environments and heritage sites.

In Finland the Ministry of Employment and the Economy commissioned the creation of a national wind atlas of places that are suitable for wind power developments. The maps can be found on the website www.vindatlas.fi and are intended as a tool for use in planning wind power development in the country. Such maps could be combined with map-referenced cultural heritage data, so as to disclose areas where development of wind power could conflict with valuable cultural environments.

In Sweden, to promote the development of wind power, the government has proposed that the building of small wind farms can be decided by local authorities. Local authorities usually have no expertise in cultural heritage, and there is therefore a danger that the cultural environment will not be taken into account. As a consequence, The Swedish National Heritage Board is considering setting up a collaboration project to study local authority plans and associated environmental decisions and landscape analyses, to see how cultural environments and the landscape have been handled. The aim of the study will be to find good examples of how cultural environments and the landscape can be handled in planning wind power developments and provide the basis for guidelines in this area.

Aside from the visual effects on cultural environments and landscapes, construction work associated with developments can affect archaeological sites. Wind farms at sea can also affect heritage sites under water. In Denmark the cultural heritage authorities have therefore entered into close collaboration with the marine authorities, and there are laid down procedures for archaeological surveys in connection with the establishment of wind farms at sea.

Hydropower

Hydropower is an important renewable energy source in many Nordic countries. In Norway, hydropower represents 98% of electricity production, in Iceland 73%, Sweden 44% and in the Faeroe Islands 39%. The need for more renewable energy calls for the development of more hydropower, and this will affect heritage sites and landscapes.

Building dams, channelling water into pipes and filling and emptying reservoirs all mean major impacts on the environment. For archaeological sites in the areas being dammed,

the consequence is that most of them will be lost. A more widespread development of hydropower resources will therefore require extensive work on recording sites in the affected areas.

There are big development plans in the Faeroe Islands, including in Eysturoy, where a large lake has been turned into a reservoir. The National Museum of the Faeroe has carried out surveys of the remains of old settlements and the cultural landscape that was flooded. For the next stage of development of this hydropower system, there are requirements for an environmental consequence analysis. Greenland also has a largely unexploited potential for developing hydropower. Such a development could affect large areas of land and lakes with archaeological sites.

In Scandinavia on the other hand there is little political will to develop more large hydropower stations, and instead the focus is on developing small-scale power stations. But these too will affect the natural and cultural environment in the affected areas.

Geothermal energy

The Icelandic authorities have been working on a national plan in which opportunities for further power development have been investigated. Power stations based on both hydropower and geothermal energy, that is to say using heat from deep in the earth, have been included in the assessment. A number of areas have been reviewed to assess the consequences of power development and in connection with this work, the cultural heritage authorities have recorded all heritage sites in and near the relevant geothermal areas. In many cases the areas most suitable for building power stations have also received a high ranking for the value of their cultural heritage sites. This includes Þeistareykir in northern Iceland. This has many heritage sites and ruins of a settlement that is unique, partly because of its location by the geothermal area. A power development here would entail the need for a major archaeological excavation of the complex of ruins.

Ground source heat

Ground source heat, that is to say stored solar energy in the upper earth layer, is a renewable energy source that can be exploited on a small scale for heating buildings and water. Establishing a ground source heating system requires construction work that may destroy any archaeological remains on the site. In Denmark especially, where the ground contains a lot of archaeological material, the development of ground source heating will often come into contact with traces of the past. This will place a burden on the archaeological museums that undertake the necessary investigations. If all the grants for changing over from oil-fired heating in Danish buildings were used to install ground source heating, this would result in 10,000 potential archaeological excavations a year.

5.3 Changes in industries, infrastructure and land use

Expansion in agriculture

A warmer climate and longer growing season will change the conditions for agriculture in the Nordic countries. The extent

to which the changed climatic conditions result in new cultivation and extension in agriculture will, however, depend on the agricultural policy of each country.

The climatic basis for an expansion in agriculture will be greatest in marginal areas. For example, a warmer climate in Arctic areas will mean better conditions for agriculture in southern Greenland. If this results in new cultivation and more intensive operations, this will represent a threat to ruins, middens and fields from the Norse culture. Today's farmers use the same areas as the Norsemen did and the conflicts could increase between preserving heritage sites from the Norse period and present day agriculture.



Modern agriculture and ruins of Norse settlement, southern Greenland.

(Photo: Claus Andreasen, Greenland National Museum and Archives)

Climate change could also initiate new methods of cultivation.

Increased rainfall could lead to farmers ploughing deeper to achieve better drainage. This would be a threat to the archaeological material that lies buried in the ground.

Cultivating energy crops

The need for bioenergy from agriculture will increase in the future, not least because of the EU directive on renewable energy. We shall therefore probably see agricultural land being used to grow energy crops to a greater extent than today. Tall, thicket-like energy crops like *Salix* change cultural environments and landscapes where grain and other low-growing crops have previously been grown.

In Sweden the study *Jordbruk, bioenergi och miljö* (Agriculture, bioenergy and the environment) was produced by The Swedish Board of Agriculture (Jordbruksverket, 2009), the Swedish Environmental Protection Agency and the Swedish National Heritage Board on behalf of the government, as part of the government's follow-up and assessment of the environmental effects of the EU agricultural policy. The report gives an account of the consequences more extensive use of Sweden's agricultural land for growing bioenergy could have on the environment. One of the conclusions is that the location and extent of the cultivation is decisive in deciding

whether its effects on biological diversity and the appearance of the landscapes will be positive or negative. When the cultivation of tall energy crops becomes too extensive or approaches valuable cultural heritage environments, the effects on environments and landscapes are negative. Deliberate control of the cultivation of energy crops will therefore be necessary.

Intensive forestry

In the Nordic countries there is great potential for bioenergy from forests. Through increased tree planting and active forestry, the forests can both help to bind CO₂ and provide a raw material for bioenergy. This is part of climate policy not just in forested countries like Norway, Sweden and Finland, but also in Iceland and Denmark, which have great opportunities to re-establish forest after earlier deforestation.

Intensive, industrial forestry can have consequences for heritage sites in forest areas. The use of heavy vehicles and machinery could increase wear and damage to heritage sites and cultural environments in the forest. Breaking up stubble and roots for producing bioenergy in particular can easily damage archaeological sites if the forestry workers do not know where the sites are situated.

Planting forest in Iceland

Since Iceland was first settled, 95% of its forest has probably been lost and soil erosion has become a major problem. Forest planting and reseeded of eroded areas are therefore being used on Iceland as important climate measures that receive considerable state support. Forest planting can, however, conflict with the conservation of archaeological sites. In many of the areas where trees are being planted, heritage sites have not yet been recorded. In some places trees have also been planted in areas with protected ruins. The introduction of larger trees like aspen and conifers from Europe and America has increased. These trees often have larger roots than Iceland's natural mountain birch and can therefore do great damage to archaeological sites.



The protected archaeological site of Biskupagarður in southern Iceland was being ploughed up for tree planting before the work was stopped.

(Photo: Inga Sóley Kristjónudóttir © Archaeological Heritage Agency of Iceland)

Industry

Reduced sea ice in Arctic areas as a result of climate change will increase opportunities for recovering raw materials in the Arctic and transporting those materials. This will create pressure on large areas of land, in Greenland for example, and could represent a threat to both the landscape and heritage sites. Recovering raw materials will lead to the development of road connections to the coast and towns, and the development of large ports and other infrastructure in the towns could also conflict with existing cultural environments. However, many of the older buildings in Greenland were prefabricated and can easily be dismantled and moved if necessary.

Tourism

When the Arctic sea ice decreases as a result of a warmer climate, the accessibility of land areas in the Arctic also increases. This can lead to increased tourism and more people coming ashore at vulnerable heritage sites. Paradoxically, climate change has also made Greenland and Svalbard more prominent as tourist destinations, and we now have what is called climate tourism. More tourists will increase the wear and tear on vegetation and on heritage sites in vulnerable Arctic areas. It also increases the risk of loose artefacts being removed from heritage sites as souvenirs.

Infrastructure

Climate change will probably lead to increased development of new infrastructure in the years to come. Higher annual precipitation and more extreme precipitation events increase the need for improvements in waterways and sewage systems. The change to a more eco-friendly transport sector will require development of public transport. District heating networks are being developed in many places to exploit heat from waste incineration plants. In areas with archaeological material in the ground, the construction work associated with such developments and changes in infrastructure will require major archaeological surveys and excavations.

Developing the Copenhagen underground

A major development of the Copenhagen underground during the period 2010 to 2019 will help to solve traffic problems in the city in an eco-friendly manner that will help to reduce CO₂ emissions. Because of this development, extensive archaeological excavations are being carried out in the five-metre-deep layers of archaeological deposits that lie below Copenhagen. These layers hold information from the early Middle Ages to today. The full archaeological excavations amount to about 11,600 m³, in addition to spot tests and preliminary studies. This will be Denmark's biggest archaeological project ever and is evidence of a major impact on Danish cultural heritage caused by climate and environmental adaptations in another sector.

Changed land use

New risk assessments as a result of climate change could put limitations on the development and use of land. More areas will

become defined in local planning as areas at risk of landslide, flood and rising sea levels. This could increase pressure on land with existing heritage sites and cultural environments. Changes in industries and settlement as a result of climate change could occur in the longer term. Among other things, conditions in the fisheries industry will probably change. Stagnation and depopulation that cause heritage buildings to become disused could easily result in the buildings decaying. On the other hand, there are also examples of cultural environments that have been saved because of little activity and renewal. Climate change will affect society in interaction with many other factors, so that the outcome for cultural heritage will often be difficult to predict.

Land use planning can be a useful tool for adapting society to a climate that is changing. The Swedish National Board of Housing, Building and Planning's (Boverket, 2010) publication *Mångfunktionella ytor. Klimatanpassning av befintlig bebyggd miljö i städer och tätorter genom grönstruktur* (Multifunctional areas: climate adaptation of existing built environments in cities and densely populated areas through green structures) has been created to give support and inspiration to the local authorities' work of adapting existing built-up areas to the climate. Green structures and open areas in cultural environments can be used, among other things, to handle increased precipitation. This is an example of climate adaptation in other sectors that can successfully be combined with the conservation of heritage sites and cultural environments.

5.4 Recommended measures

Cross-sector collaboration

Collaboration between the cultural heritage authorities and other relevant sectors in climate-related issues is essential for safeguarding cultural heritage interests. Only in this way can cultural heritage considerations be integrated into social planning in the areas affected by climate change.

In many of the Nordic countries, the cultural heritage authorities already collaborate with other authorities in flood defences and the protection of heritage sites. In Finland, for example, the National Board of Antiquities is working with regional and national authorities and Finland's environmental administration to map out areas with cultural environments and archaeological sites of national interest that could be affected by flooding.

In Denmark, the Heritage Agency of Denmark has been working with the Danish Coastal Authority to include heritage sites in flood scenarios that the authority has prepared. Mapping and securing of cultural heritage along the coast will be even more important in the future because of the rising sea levels.

Dialogue and collaboration with public authorities in areas such as agriculture, building, energy and contingency planning will also be vital. These are all sectors that will be greatly affected by climate change.

Collaboration on wind power

In Sweden, the Swedish National Heritage Board has had extensive collaboration with other authorities on the issue of wind power. The Swedish Energy Agency's education programme *Vindval* is one of the arenas for collaboration. One of the programme's projects is called *Vindkraft och kulturmiljö* (Wind power and cultural environments) and will analyse land-based wind power's effect on the cultural environment with regard to archaeological heritage, buildings, landscapes and biological cultural heritage. The Swedish National Heritage Board has also contributed to the website www.vindlov.se, which is coordinated by the Swedish Energy Agency on behalf of the government. The website gives information about the whole process of approving a wind power station and what needs to be considered at each stage of the process, whether for a small private windmill or a major wind farm at sea. The Swedish National Heritage Board has also created a checklist that can be used to investigate the environmental consequences in advance of new wind power projects and has been involved in two publications from the Swedish National Board of Housing, Building and Planning (Boverket, 2009a, 2009b) about planning wind power stations.



Collaboration is needed across sectors to take account of all landscape interests when establishing wind power stations.

(Photo: Bengt A. Lundberg © Swedish National Heritage Board)

Collaboration with various industries

The dialogue between the cultural heritage authorities and the agricultural industry on land clearing and cultivation will become even more important as climate change creates new conditions for agriculture.

Careful cultivation in Bornholm and Skåne

At the two classic archaeological Iron Age sites Uppåkra in Skåne and Sorte Muld on the island of Bornholm, various cultural heritage interests have been collaborating with farmers over the conservation of the archaeological heritage in the ground. With the aid of information and informal meetings with the farmers, the land is now being cultivated with more care. These measures are based on recommendations (Danmarks Jordbrugsforskning, 2002) for reducing soil erosion. The methods recommended lead to reduced use of fuel and thus reduced CO₂ emissions, while at the same time saving the archaeological items in the ground from harm. One recommended measure is for example to plough, harrow and sow in one process, so that the soil is disturbed less often. Another measure is to reduce ploughing depth and the speed of ploughing. More such areas that should be cultivated carefully to protect archaeological heritage could be chosen for further collaboration with the agricultural industry.

Plans for increased tree planting and intensive forestry in the Nordic countries will increase the need for collaboration with the forestry industry. Such a collaboration could help to prevent archaeological sites from being destroyed during felling and the extraction of stubble and roots for energy purposes. Even when forest owners have access to map-referenced heritage data, this does not help the many sites that are not recorded. It has also been found that the map references in some older records are not precise enough. Not just felling, but also the planting of new forest can damage archaeological sites. When we see that new forest has been planted on protected heritage sites in Iceland, it is clear that more dialogue is needed with the forestry industry.

Improved accessibility to vulnerable heritage sites in Arctic areas will require tourism to be regulated. The cultural heritage authorities can collaborate with the tourist industry and the relevant authorities on this. Tourism can be controlled with the aid of access regulation to areas with valuable heritage sites. This is done for example in the national park in northern and northwestern Greenland. The cultural heritage authorities can also help in training tourist guides.

Cultural heritage authorities should also work with the building industry and building goods manufacturers to find the right materials and technical solutions. It is important to maintain the availability of traditional materials, such as timber materials of high quality and porous paints and mortars. This is a prerequisite for repairing heritage buildings and for maintenance that can prevent climate-related damage. One could also consider collaboration in product development. The development of thin, highly efficient insulation materials for use in buildings, for example, would have made it easier to insulate historic buildings without overly changing the original proportions. Such insulation has already been developed for use in aviation, but is too expensive at present to be used in buildings.

Work on legislation, regulations and standards

The cultural heritage authorities should take the opportunities that exist for influencing work on legislation and regulations regarding heritage sites and cultural environment, where climate change is involved. This may for example apply to energy use in heritage buildings. If the cultural heritage authorities play an active role in consultation processes, heritage buildings can be taken into account in legislation and regulations. In the Faeroe Islands, a modern, national building law is being prepared for the first time, which gives the cultural heritage authorities a particular opportunity to influence the work of shaping the legislation.

Work on standardisation can be another way of creating good guidelines for energy efficiency in heritage buildings.

Standard for energy efficiency in heritage buildings

Following a proposal from the Directorate for Cultural Heritage in Norway, a European standard will be created for energy efficiency measures in protected and other heritage buildings. This has been decided by the Committee for the Conservation of Cultural Property in the European standards organisation CEN. Countries that are members of CEN are obliged to implement all European standards and adopt them as national standards. In essence following such a standard is voluntary, but it can be used as a reference in insurance clauses, in legislation or in other connections and in this way become binding.

Developing knowledge and expertise

More knowledge and research is needed about how climate-related change in other sectors affects heritage sites and cultural environments. Such knowledge is needed in cultural heritage administration as well as in sectors that affect cultural heritage, and it will be important to transfer knowledge and information to these sectors.

Among other things, there is a need for more cross-sector research and information transfer about energy efficiency in heritage buildings. As a rule, old buildings are less energy efficient than new ones, but on the other hand, new construction entails great climatic and environmental impact. The cultural heritage sector should also develop more knowledge about the advantages of heritage buildings in climate and environmental questions and make use of this knowledge in social debate.

Because climate change affects both social structures and people, social sciences and humanities research relating to the heritage field will also be needed.

Information and advice

The cultural heritage authorities must be able to provide information and advice to owners and administrators of heritage sites about climate-related social changes that affect them. This may, for example, apply to information about how energy saving measures can be carried out on heritage buildings. Building owners are largely dependent on marketing and information from suppliers when choosing building goods and energy saving equipment. Suppliers are not normally concerned about whether what they provide reduces the heritage value of a building. The owners and administrators of such buildings should therefore seek information and advice from the cultural heritage authorities and other serious agencies that are not governed by commercial interests.

Public information about energy saving should allow for the fact that many buildings have a heritage value and the cultural heritage authorities must work at getting the special considerations for heritage buildings incorporated into such information. In the same way, they must work to get considerations of archaeological heritage, cultural environments and landscapes included in public information about, for example, developing renewable energy sources. It is important, however, that the cultural heritage authorities are able to communicate their views and attitudes in such a way that they are perceived as constructive in relation to society's goals for energy saving and reducing greenhouse gas emissions.

Climate and energy requirements for one's own organisation

By setting requirements for energy efficiency in buildings and equipment, public agencies can contribute to reducing energy consumption and greenhouse gas emissions. A climate-aware cultural heritage authority must demand that the implemented energy saving measures do not reduce the heritage value of the buildings. In Denmark, both private and public organisations can choose green electricity that is produced by wind power instead of oil and coal. In this way, both the cultural heritage authorities and private owners can help to reduce greenhouse gas emissions and mitigate climate change.

The public cultural heritage administration can also be more conscious of travel in its own organisation. Where possible, one can for example use video conferencing and other technology that can help to reduce the number of journeys that cause greenhouse gas emissions.

5.5 Conclusion

Climate change is bringing forth adaptation and mitigation in a number of sectors and part of the transformation processes will affect the management of cultural heritage. These changes are happening already, but will probably accelerate in the

future. This requires assertive cultural heritage authorities that engage in dialogue with relevant sector authorities, businesses and owners.

It is difficult to predict all the future consequences that climate-related changes in other sectors will have for the management of cultural heritage. It is even more difficult to predict how significant those consequences will be. The most obvious challenge today to heritage buildings is the increasing demand for energy efficiency. For archaeological heritage and landscapes, increased development and production of renewable energy are probably the changes in other sectors that will have the greatest significance.

The owners and administrators of cultural heritage sites will be increasingly forced to consider climate-related issues that affect the management of heritage sites. The challenge for cultural heritage administration in the future will be to put forward strategies for how the cultural heritage sector can help to resolve climate issues, while at the same time taking care of heritage values.

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Climate Change and Cultural Heritage in the Nordic Countries

The project *Effects of Climate Change on Cultural Heritage Sites and Cultural Environments* is a collaboration between the cultural heritage administrations of seven Nordic countries: Iceland, Greenland, the Faeroe Islands, Denmark, Sweden, Finland and Norway. The aim of the project has been to assist the cultural heritage administrators in meeting the anticipated climate change and to strengthen collaboration and network building between the Nordic cultural heritage administrators.

The publication *Climate Change and Cultural Heritage in the Nordic Countries* contains the main results of the project's work. The report consists of two parts, part one of which discusses the anticipated effects of climate change on cultural heritage sites and cultural environments in the Nordic countries. Part two addresses what consequences the climate change will have for the management of heritage sites and includes the project group's recommendations for handling these consequences.

