Archaeological Review from Cambridge
Department of Archaeology, University of Cambridge, Downing Street, Cambridge CB2 3DZ, United Kingdom

Open Access Metadata Form

Modern Climate Change and the Practice of Archaeology

Volume 32.2, November 2017

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Article Title: Mitigating Climate Change Effects on Cultural Heritage Sites?

Abstract (300 words or less):

How fast do archaeological deposits, soil features and artefacts degrade? Is it possible to preserve archaeological remains *in situ* without significant loss of information potential? Modern archaeology and heritage management needs to prepare for and respond to modern climate change, causing higher temperatures, increased and more concentrated precipitation events and changes from snow to rain which may lead to an irrevocable loss of information. This paper suggests sets of threshold levels and threat evaluations of heritage sites, possible mitigation and management strategies, on a basis of archaeological observations and results of palaeoecological and geochemical analyses of archaeological deposits from rural sites in northernmost Norway, combined with climate data and continuous monitoring of soil temperature, moisture and redox potential in sections. This data, collected in an interdisciplinary research project, constitutes the basic research material for evaluations of conservation state and preservation conditions. Decay studies indicate that many site types may be at risk with the predicted climate change. The results have consequences for heritage management of a large number of sites from all periods.

Subject Keywords (Keywords or short phrases to describe the article):

Climate change; arctic archaeology; cultural heritage management; in situ versus ex situ preservation

Sponsorship (Information about sponsoring agencies, individuals, or contractual arrangements):

NIKU – Norwegian Institute for Cultural Heritage Research (strategic institute research grants)

Research Council of Norway, project number 212900 (Archaeological Deposits in a Changing Climate… (InSituFarms)) https://www.forskningsradet.no/prosjektbanken/#/project/NFR/212900 ;

Research Council of Norway, project number 208429 (InSituSIS)
https://www.forskningsradet.no/prosjektbanken/#/project/NFR/208429

Mitigating Climate Change Effects on Cultural Heritage?

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Introduction

As part of cultural heritage management in Norway, from 2012 to 2016 I had the privilege of working on two interdisciplinary research projects, mainly funded by the Research Council of Norway: 'Archaeological Deposits in a Changing Climate: *In Situ* Preservation of Farm Mounds in Northern Norway (InSituFarms) 2012–2016' and '*In Situ* Site Preservation in the Unsaturated Zone (InSituSIS) 2011–2015'. The goal of these projects was to try to preserve as many archaeological heritage sites as possible *in situ*. This practice has been implemented in Norway since the signing of the Valletta Treaty (Council of Europe 1992), which also stipulates that preserved sites must be monitored and maintained. The rationale behind this practice is that the next generation of archaeologists will have more advanced knowledge and methods to gather further information from the buried materials than what is possible to recover at present.

The ultimate goal of the projects was to provide tools for heritage management in order to enable decisions on whether to preserve sites *in situ* or *ex situ*. To achieve that goal, it was necessary to study which parameters most affect and/or provide information on the preservation of archaeological sites—physical disturbance through infrastructure pro-

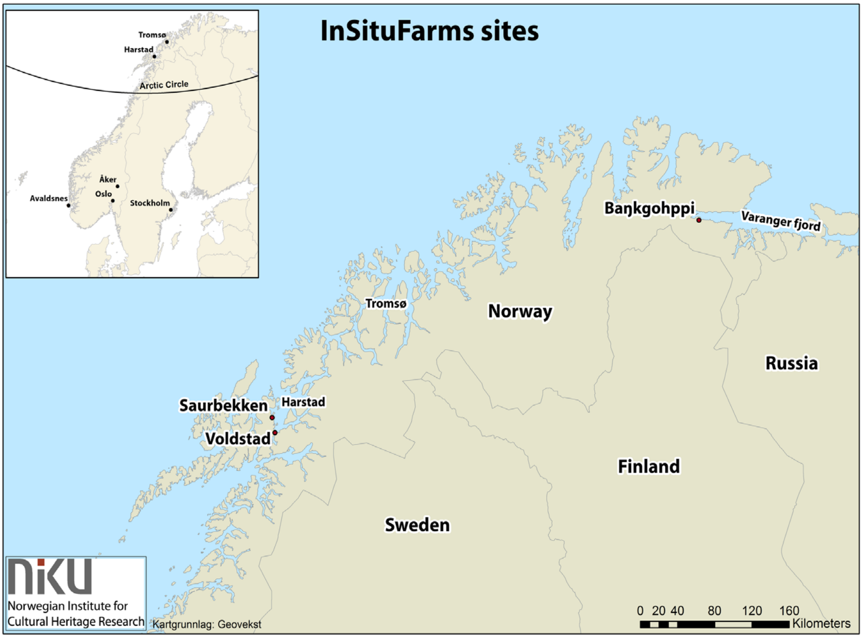

Fig. 1. Map of InSituFarms case sites, the farm mounds Voldstad and Saurbekken near Harstad in Troms County and the Neolithic midden at Baŋkgohppi by the Varanger fiord in Finnmark County. Comparative sites are Åker (farm mound) and Avaldsnes (settlement deposits and burial mound) (map by Hafsal/NIKU, after Martens 2016: Fig. 2).

jects or changed use, vegetation encroachment, soil water content and soil temperature, soil oxygen content or redox parameters.[1] Measurements of redox potential may be used to evaluate preservation conditions where direct oxygen content measurements are impractical or to supplement information to oxygen content measurements. If conditions are reducing, that means that the site is stable, but if they are oxidizing, the site is under active degradation and thus threatened (Huisman 2009: 177–212; Martens and Bergersen 2015; Vorenhout et al. 2011).

Modern climate change is an external factor significantly influencing the preservation of cultural heritage sites on a global scale, causing higher

1 Redox parameters are geochemical parameters indicating if the conditions for preservation are reducing or oxidizing.

temperatures, increased and more concentrated precipitation events and the replacement of snowfall with rainfall. Studies indicate that northern Norway is likely to be more influenced by climate change than the rest of the country and might experience all of these climatic changes (Alfsen et al. 2013; Hanssen-Bauer et al. 2015; IPCC 2013). The polar regions, including Arctic Norway, may act as the bellwether for change occurring in the rest of the world, making this a logical outset for studies. Precipitation change from snowfalls to heavy rainfalls may result in avalanche and landslides, as seen on the Arctic archipelago of Svalbard in winter 2015–2016 and 2016–2017 (Nordlys 2017; Nrk.no 2016) and in Greenland during 2017 (Jordskjelv.no 2017; Knr 2017). Further still, an avalanche or landslide may not only damage people and property, but may even carry away a whole archaeological site, with no chance of rescuing information from it.

This paper intends to present some of the parameters that have the largest impacts on heritage site preservation, define possible threat situations and threshold levels as a set of controls to decide if a site is safely preserved or under threat and, if a site is threatened, suggest which mitigation measures might prolong possibilities for *in situ* preservation. Two archaeological site types, which are numerous in northern Norway, were chosen as case sites: Medieval farm mounds and Gressbakken houses (fig. 1). Medieval farm mounds, or settlement mounds, were chosen as sites because they constitute the most numerous rural archaeological remains, equalling or surpassing the preserved deposits in Medieval towns (Martens 2016: 15–19). The majority of these mounds are found north of the Arctic Circle, represented here by the settlement mounds at Voldstad and Saurbekken, both in Harstad municipality, Troms County. Further north in Arctic Norway, a Neolithic house type known as a Gressbakken house was chosen as a case study site because walls and middens from the houses are still visibly preserved today. The site used here is a wall and midden at Baŋkgohppi in Nesseby municipality, Finnmark County (Martens et al. 2016: 10–11).

Materials, Methods and Results

The overall aim of the project was to evaluate the state of preservation of the deposits, as well as to sample for soil macrofossils, pollen and geochemical samples to determine continued preservation conditions. Mon-

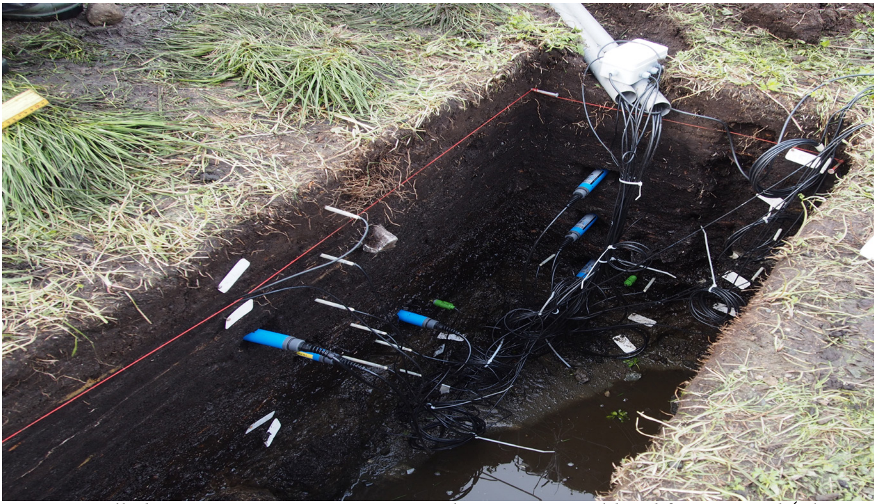

Fig. 2. Installed monitoring equipment in trench sections at Voldstad farm mound (photograph by VVM/NIKU).

Fig. 3. Decorated bone artefact from Baŋkgohppi, typical of Gressbakken settlements. Scale is 5cm (Photograph by VVM/NIKU). Fig. 4. (above right) Snails and shellfish from the midden deposits at Baŋkgohppi. Scale is 30cm (photograph by VVM/NIKU).

itoring equipment was installed to enable the evaluation of the long-term preservation potential: these measured temperature, soil humidity and redox parameters before the trenches were backfilled (fig. 2) (for results of the monitoring, see Martens 2016 and Martens et al. 2016). The soil samples were analysed for organic matter content, water content, porosity, pH, conductivity and a range of geochemical parameters defining the

Samples / sensors	Depth (m)	Depth (masl)	Stratum	Organic matter (%)	Water content (%)	pH	Conductivity uScm $^{-1}$	Preservation: Organic material	Preservation: Inorganic material	Preservation: Redox conditions *	Preservation: Archaeological state *
Sensor 4 west	0,24	30,91	Layer 2	68	72	7,2	166	excellent	medium	A5	A3-4
Sensor 5 west	0,40	30,75	Layer 3	47	68	7,4	166	excellent	medium	A5	A4
Sensor 6 west	0,56	30,59	Layer 4	59	69	7,6	379	good	good	A5	A4-5
Redox 1 west	0,57	30,58	Layer 4								
Sensor 1 north	0,26	30,89	Layer 2	57	69	7,3	65	excellent	medium	A5	A3-4
Sensor 2 north	0,44	30,71	Layer 3	52	69	7,7	291	good	good	A4	A4
Sensor 3 north	0,52	30,63	Layer 4	43	61	7,3	424	excellent	medium	A5	A4-5
Redox 2 north	0,58	30,57	Layer 4-5								
Sample A east	0,51	30,64	Layer 3-4	35	60	7,8	218	good	good	A4	A4-5
Sample B east	0,57	30,58	Layer 4	42	62	8,0	443	good	excellent	A5	A4

Low organic matter 10%
Medium organic matter 10-20%
High organic matter 30-40%
Low water content10-20%
Medium water content 30-40%
High water content 50-60%

Lousy to poor
Medium
Good to excellent

Oxidizing condition
Reduced condition
* SOPS : NS 9451:2009

Table 1. Geophysical, geochemical and archaeological evaluations of preservation conditions and state of preservation in the monitored deposits at Voldstad (Bergersen and Martens, after Martens 2016: 87 Table 14).

Samples / sensors	Depth (m)	Depth (masl)	Layer	Organic matter (%)	Water content (%)	pH	Conductivity uScm $^{-1}$	Preservation: Organic material	Preservation: Inorganic material	Preservation: Redox conditions *	Preservation: Archaeological state *
Sensor 4 west	0,30	14,10	Layer 3	4	6	8,3	226	poor	excellent	A2	A3-4
Sensor 3 west	0,05	13,75	Layer 2	10	16	7,7	365	poor	good	A2	A3
Redox 1 west	0,20	13,60	Layer 4	12	12	8,2	297	medium	excellent	A3	A4
Sensor 1 west	0,37	13,53	Layer 4	4	1	8,8	209	poor	excellent	A2	A4
Sensor 5 west	0,34	13,46	Layer 7	5	11	8,7	221	poor	excellent	A2	A3
Redox 2 west	0,63	13,17	Layer 8	3	11	9,2	168	poor	excellent	A2	A3
Sensor 6 west	0,86	13,04	Layer 9	2	6	8,9	144	poor	excellent	A2	A2
Sensor 2 east	0,38	13,52	Layer 5	3	9	8,9	210	medium	excellent	A3	A3
Profile south	0,70	13,10	Layer 8	10	18	8,5	252	medium	excellent	A3	A3

Low organic matter 10%
Medium organic matter 10-20%
High organic matter 30-40%
Low water content10-20%
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Table 2. Geophysical, geochemical and archaeological evaluations of preservation conditions and state of preservation in the monitored deposits at Baŋkgohppi. In this context, inorganic includes bones (Bergersen and Martens, after Martens 2016: 84 Table 12).

redox potential. The farm mound deposits all had high organic matter and high water content, with neutral to slightly basic pH and low conductivity (table 1). These conditions indicated good to excellent preservation conditions for organic material and medium to good preservation conditions for inorganic material, such as glass and metals.[2] The state of preservation perceived by the archaeologists on site varied from medium at the top to good or even excellent for the Medieval settlement deposits. The Neolithic midden layers all had very low organic matter and water content, with high pH and relatively low conductivity (table 2). These conditions indicate poor to medium preservation of organic botanical matter, but good to excellent preservation of inorganic material, including bone.[3] The alkaline environment in the shell middens preserves bone and shells excellently, enabling the preservation of the artefacts and the possibility of studying dietary preferences in the past (figs. 3–4).

Soil samples from both sites were also submitted for degradation tests, carried out at the National Museum of Denmark (Matthiesen 2007; Matthiesen et al. 2014). These tests indicated that the Medieval farm mound deposits were best preserved when kept very wet and cold, while the Neolithic midden deposits were better off as dry and cold as possible, especially since increased precipitation in the form of rain might accelerate the degradation of the hitherto well-preserved calcareous remains (Hollesen et al. 2015; Hollesen and Matthiesen 2015). For every 1°C increase in temperature, decay rates may increase by at least three per cent for the Neolithic middens and up to 14 per cent for the organic Medieval deposits (Hollesen et al. 2016; Martens et al. 2016). This means that, if the predicted climate change projection comes to fruition, many of the archaeological sites in northern Norway are at risk of disappearing or at least losing their scientific potential by the year 2100 (Hanssen-Bauer et al. 2015; Hollesen et al. 2015; Martens et al. 2016).

2 The state of preservation and preservation conditions are decided following the Norwegian Standard, NS 9451 from 2009 (NS 9451: table 1), cf Martens and Bergersen 2015: table 1. There are five values: 1=lousy, 2=poor, 3=medium, 4=good and 5=excellent.

3 One discussion between archaeologists and botanists in the interdisciplinary project was about how to categorize bone material. From an archaeological perspective, it is considered organic matter, but, from a biological perspective, it is considered inorganic, as botanical organic materials are more immediately impacted by changes in preservation conditions.

Threshold Levels, Heritage Site Evaluation and Mitigation Measures

To ensure that part of our archaeological heritage is preserved *in situ* for the future, we may have to accept that some must be lost or preserved *ex situ*. Values ascribed to sites regarding their scientific potential and significance should be the deciding factor of heritage management strategies, evaluating all possible risk factors. The most important parameters with which to characterize preservation are:

(a)organic matter content, to indicate which artefacts and ecofacts may be preserved;

(b) oxygen content or redox parameters, to see if conditions are stable or not;

(c) soil temperature, to see the extent to which deposits are affected by air temperature (it is an assumption that lower soil temperatures are better for preservation);

(d) soil humidity, to indicate which artefacts and ecofacts may be preserved and to see to what extent the deposits are affected directly by precipitation;

(e) pH, to be used as an indicator for which artefact and ecofact types may be preserved (this differs considerably between acidic and alkaline environments);

(f) soil porosity, to see how easily oxygen may penetrate into the deposits;

(g) vegetation encroachment, to see if physical disturbances are a likely occurrence (Martens 2016: 92; Martens and Bergersen 2015: 69).

I have tried to define the most likely threats to site preservation and to set up threshold levels for when preservation conditions might change from safe to uncertain/at risk or even threatening. The aforementioned threats build on the Norwegian Standards' requirements for condition assessment and recording for automatically protected archaeological heritage (NS 9450) and on their requirements for environmental monitoring of archaeological deposits (NS 9451). The following threats are considered the most

	% change of soil moisture	% change of surface damage	°C change of temperature	% change of decay rate	% loss/damage to site caused by continued use	% loss/damage to site caused by new use/ development
	11-	11-	2-	21-	21-	11-
	06-Oct	06-Oct	01/01/2009	Nov-20	Nov-20	06-Oct
	0-5	0-5	0-0.9	0-10	0-10	0-5

Table 3. Threshold levels defined as change in preservation conditions (Martens, after Martens 2016: 97 Table 16).

Stage (work phases)	Objective	Relevant subtasks
Prepare	*Input*	*Organisation and work plan for the analysis*
S1 **D**escribe	Historical character of the area of analysis	Establish a knowledge base, collate, describe and process information about the origins, development and character of the area
S2 **I**nterpret	Historical meaning of the area	Explore the area's historical legibility, its significant and communicative contents, integrity, authenticity and overall condition
S3 **V**aluate	Value and potential of the area	Assess the value, development potential, vulnerability, tolerance and capacity for change of the cultural and historical resources
S4 **E**nable	Active intervention	Define the potential field of action for the cultural heritage, suggest strategies and principles, instruments and concrete measures for management and development
Summarise	*Output*	*Summary of the contents, results and recommendations of the analysis*

Table 4. The DIVE method (redrawn by Martens from Reinar and Westerlind 2010).

common to continued site preservation: damage from continued, everyday use; new use or development; infrastructure projects in maintenance or development; temperature change (air/soil) and changes in precipitation (less/more/other) or surface damage (for instance, from erosion) (Martens 2016: 99; table 17). To monitor these threats, I have defined the following threshold levels (Martens 2016: 97; table 16), with the exception of the percentage change in soil moisture, which was suggested by Richard Hughes (1999): percentage change in soil moisture (Hughes 1999), percentage change in surface damage (for instance, as caused by erosion), temperature change (measured in °C), percentage change in decay rates, percentage loss or damage to a site via continued traditional use and percentage loss or damage caused by new use or development (table 3).[4]

These parameters may need some interpretation. For instance, if soil moisture content increases, that is good news for organic-rich deposits. However, it is detrimental for dry sites like the Stone Age middens. For all site types, soil temperature decrease is positive, whereas any increase is negative. Sites with porous deposits are fragile and immediately affected by changes in ambient temperature, whereas the more compact deposits react more slowly, if at all, to ambient temperature changes. Surface damage caused by erosion is probably the largest threat to any site type, independent of deposit composition or dating. Encroaching vegetation is another threat caused by climate change that is relevant to all site types and dates. Damage or loss to sites caused by continued, traditional use, such as field ploughing, is very difficult to monitor, but if field walks and/or metal detecting bring new artefacts to the surface every year, that is a clear indication of damage. To monitor this type of loss, one might consider using repeated geophysical prospection methods. The same warning signs and methods may be used to check damage caused by the new use or development of a site, for instance extracting gravel, ploughing previous woodland areas or planting forests on previous arable land. Finally, a new method has been developed to assess glacier vulnerability in Greenland using satellite imagery (Jex 2017). Satellite imagery and laser scans may be used to monitor cultural landscapes and widespread heritage sites, and recent experiments collecting imagery from drones to monitor site vulnerability on Svalbard have proven successful (Thuestad et al. 2015).

If sites are threatened—that is, if one or more of the threshold levels indicate immediate risk—all levels of heritage management need mitigation measures and selection strategies for whether to preserve sites, either through mitigation or excavation. There are different ways to evaluate the

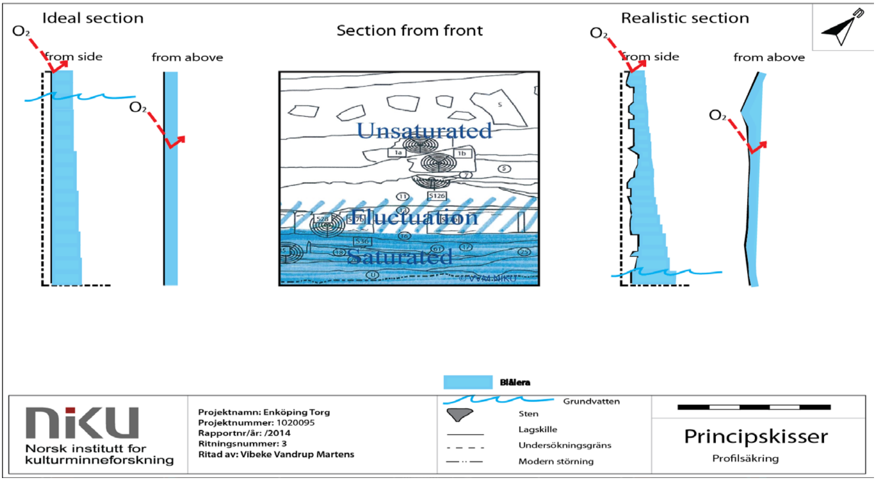
[4] These values are inspired by Hughes, by experience from research projects and by my personal experience as a field archaeologist since 1990.


Fig. 5. (left) Securing a section with clay, lifted into the trench by the digger. It was then padded on by hand to protect the installed monitoring equipment (photograph courtesy of Michel Vorenhout, MVH Consult). Fig. 6. (right) Securing a section with clay. For the rest of the trench, the digger pushed the clay towards the section to protect the deposits from oxygen influx and dewatering (photograph by VVM/NIKU).

scientific potential and significance of sites. For instance, DIVE analysis—Describe, Interpret, Valuate, Enable (Reinar and Westerlind 2010)—evaluates eligibility, significance, communicative contents, integrity, authenticity and overall condition to assess value, vulnerability and development potential at a site (table 4).[5] This method and a paper currently being designed by the Swedish Directorate for Cultural Heritage for archaeological heritage sites (RAÄ 2015) have been inspired especially by the Historic England guide on *Conservation Principles, Policies and Guidance* (2008) and the *Australia ICOMOS Charter for Places of Cultural Significance* (Australia ICOMOS 2013). All of these evaluation systems adhere to the *Faro Convention* (Council of Europe 2005) on the value of cultural heritage for society. Sites must be evaluated for the stories they communicate and the meanings they hold for both local communities and international audiences (Pocock et al. 2015). If a site is deemed important enough to preserve, the next logical steps are developing documentation methods, mitigation measures and ways to communicate the hidden heritage.

A mitigation action tested in the project involved securing a section in an infrastructure trench through a farm mound. Non-marine clay was pushed

[5] The DIVE method has mainly been developed for and used on built heritage, but it may be used also on archaeological sites.



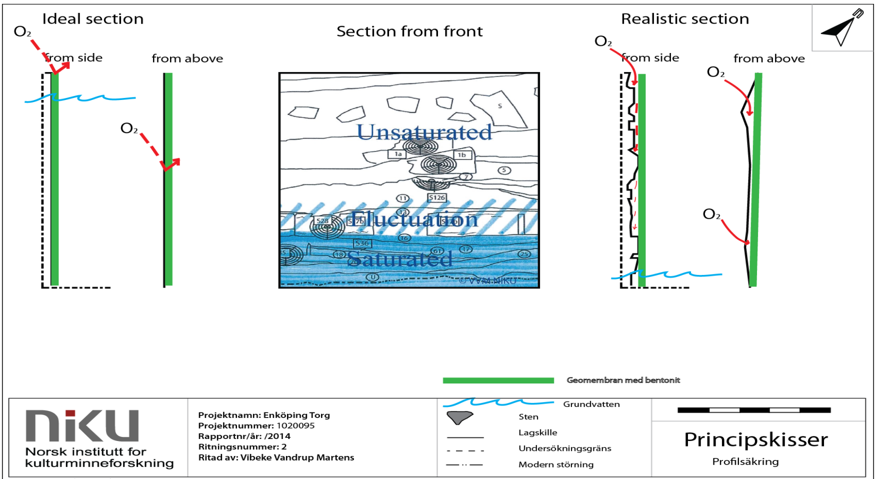


Fig. 7. (top) Principle sketch of securing a section with non-marine blue clay. It must be non-marine, as marine clay contains sulphides that might accelerate degradation of organic remains. Clay works as an efficient sealant against dewatering and oxygen entry, no matter the complexity of the section, but it must be pushed directly onto the section to have optimal effect. Fig. 8. (bottom) Principle sketch of securing a section with bentonite-filled geotextile mats. These mats only work properly against oxygen entry and dewatering on completely straight sections that are permanently in contact with groundwater. If the mats dry out, the bentonite (clay mineral) will crumble and fall down. Preferably, bentonite geotextile mats should be used only on flat, even surfaces at the bottom of trenches and in permanent contact with groundwater (drawings by VVM/NIKU).

Fig. 9. Examples of surface water hitting non-permeable surfaces or permeable surfaces. This was presented as part of the UrbanWATCH project (Cultural Heritage and Water Management in Urban Planning; Harvold et al. 2015; photograph and graphics by Anna Seither, NGU, used with permission).

towards the section, slowing down the rate of dewatering and reducing oxygen influx into the archaeological deposits (figs. 5–6).[6] This gave immediate measurable effects, lowering the soil temperature and increasing soil moisture. Clay was hand padded onto a part of the section, where monitoring equipment had been previously installed, in a layer thickness of 10–20cm and up to 35cm at the bottom of the trench (fig. 7), while a comparable amount of clay (minimum thickness 10cm) was pushed into place by the digger along the rest of the section. Previously, clay has been used to plug sloping trenches, thereby slowing down dewatering; that method was first tested by the author to secure a section in 2007. Clay acts as a sealant both in saturated and unsaturated deposits and in the fluctuation zone, and it is not vital that the sections or areas are straight and even (fig. 7). In contrast, bentonite-filled geotextile mats require flat, even surfaces and constant contact with groundwater to maintain their sealing powers (fig. 8). It may even be possible to secure whole sites by overlaying them with a 10–20cm layer of clay. This might be a relatively simple and cost-efficient way to safeguard larger areas. However, complete site coverage has not yet been tested, as it could conflict with the Cultural Heritage Act (1978), which clearly states that sites must not be covered: in some cases, one may therefore need to choose between site recognizability and site preservation. Clay coverage can be used both at rural sites and in urban settings. In the latter case, archaeological remains are often covered or hidden anyway and, consequently, covering them with clay should not cause conflict.

[6] It must be non-marine, as marine clay contains sulphides which might accelerate degradation rather than the opposite, wanted effect.

Another related mitigation measure to aid the preservation of organic matter is the process of directing excess surface water into the archaeological deposits rather than into increasingly larger sewage systems. Water from intense precipitation events is a growing problem, primarily in densely populated areas. Many surfaces are covered with non-permeable materials, such as asphalt, and this increases pressure on sewage systems. However, research projects and the practical implementation of research results have demonstrated that more than one problem may be solved by creating more urban green areas and permeable surfaces (Boogaard et al. 2016; Harvold et al. 2015; Rytter and Schonhowd 2015). Both outcomes would improve air quality and dispose of excess surface water that might infiltrate deposits, thus securing both the wooden foundations of standing buildings and organic-rich archaeology (fig. 9). In addition, more green areas improve the aesthetics of urban settings. This feature, as well as the above-mentioned benefits, would create better living spaces.

During the project, another possible measure was discussed when looking at the results of the geochemical analyses, monitoring data and degradation experiments (Hollesen et al. 2016; Martens et al. 2016): spreading chalk on top of sites with lots of calcareous remains, such as shell middens or cemeteries. This measure secures an alkaline environment and prevent loss of information that might be caused by environmental changes produced by dewatering. It should be a relatively simple, low-cost and non-invasive measure, as chalk may simply be spread on top of a site and left to be soaked in by the rain. However, this method has yet to be tested, and one should be cautious in using it. More specifically, one needs to decide that such calcareous remains are the most important remains to preserve at that specific site, because securing an alkaline environment in the deposits may lead to further loss of other organic components that require an acidic environment to survive.

Conclusion

It is possible to see how climate change leads to escalating degradation, mainly through changes in precipitation (less snow and more frequent and heavy rainfall) and temperature increase. Mitigation measures should be sustainable; they should be fairly manageable and affordable. If possible, they should also be immediately distinguishable from the original archaeology, so that future investigations can easily tell them apart on site. For farm mounds, Medieval towns and other sites with organic-rich deposits, water infiltration may work wonders. For sites with dry, calcareous remains, such as middens or burial sites from all periods, it is important to keep a dry and alkaline environment. Vegetation should be checked at all site types, and large trees with deep penetrating roots, as well as other physical disturbances, should be avoided if possible. Disturbed or threatened areas may be secured with clay coverage.

In order to preserve archaeological information from at least some sites in the future, heritage management and researchers will have to cooperate in choosing between sites. There is not enough funding to save all sites, either *in situ* through mitigation measures or *ex situ* through investigation and documentation. This means that one must choose which sites to preserve and which sites to let go, and, preferably, that choice should not be random or made solely by the environment. Rather, it should be an informed and deliberate decision based on scientific potential, threat evaluations and threshold values.

Acknowledgements

I'd like to thank the Norwegian Council for Research for funding the research projects; Archaeological Deposits in a Changing Climate. In Situ Preservation of Farm Mounds in Northern Norway (InSituFarms) 2012–2016; https://www.forskningsradet.no/prosjektbanken/#!/project/212900/no

(Sub project financed by Terrestrial Flagship, FRAM research centre 2013–2015: Archaeological Deposits in a Changing Climate. In Situ Preservation of Farm Mounds in Northern Norway. Case Varanger, Finnmark) and In Situ Site Preservation in the Unsaturated Zone (InSituSIS) 2011–2015; https://www.forskningsradet.no/prosjektbanken/#!/project/208429/no.

Thanks go to all the project partners, researchers from Norway, Denmark and the Netherlands, and local and regional heritage management from Northern Norway for their valuable and active contributions. NIKU (Inga Fløisand, Elin Rose Myrvoll, Knut Paasche); Bioforsk/NIBIO (Ove Bergersen, Øyvind Rise); Tromsø Museum, Tromsø University (Keth Lind);

Troms County Council (Ragnhild Myrstad); Archaeological Museum, University in Stavanger (Paula Utigard Sandvik); MVH Consult, NL (Michel Vorenhout); National Museum of Denmark (Jørgen Hollesen, Henning Matthiesen). Thanks also to all the people in the UrbanWATCH project.

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