



REMAINS of Greenland

REsearch and **MA**nagement of **AR**chaeological sites **IN** a changing environment and **SOCIETY**

The National Museum of Denmark

The National Museum of Greenland

The Center for Permafrost (CENPERM), University of Copenhagen

Funded by *VELUX FONDEN*



REMAINS of Greenland



REMAINS is a co-operation between the National Museums of Denmark and Greenland and Center for Permafrost, University of Copenhagen. The project will improve the understanding of processes controlling the preservation of archaeological sites in Greenland and provide research based tools that can be used for locating and managing sites at risk.

Front cover: The Qajaa kitchen midden located at the Ilulissat Icefjord in Western Greenland.

This page: Some of the extraordinary archaeological finds from Greenland. From the left: Knives with preserved wooden handles (Qajaa, Saqqaq culture), carved figures of bone (Thule, Dorset culture), preserved textiles (Ikigaat, Norse settlers), and human remains (Qilakitsoq, Thule culture)

REMAINS of Greenland

Introduction and aims

Archaeological sites in Greenland represent an irreplaceable record of unusually well-preserved material remains covering over 4000 years of human history. The cold climate has offered unique preservation possibilities and several extraordinary finds of organic remains such as wood, bone, textile, fur and ancient DNA have been made (Hart Hansen *et al.*, 1991; Berglund, 2000; Østergaard, 2004; Rasmussen *et al.*, 2010; Grønnow, 2012). Out of the more than 6000 archaeological sites currently registered in the Greenland Heritage Database, only very few have been excavated and it is anticipated that thousands of sites are awaiting discovery in the unexplored parts of the country. The potential of archaeological sites in Greenland to provide further spectacular finds and thus novel contributions to the understanding Greenland's and Arctic history is therefore very high.

However, it is only a matter of time before this potential diminishes. Climate change is detrimentally affecting preservation conditions, which is leading to an accelerated destruction of archaeological sites. It is therefore urgent to identify and classify the different threats posed by climate change in order to act in due time and safeguard important parts of Greenland's history.

REMAINS is initiated as a direct response to these threats and to the enormous challenge the National Museum of Greenland is currently facing. The aims of the project are:

- To advance the basic understanding of how climate change influence the preservation of archaeological sites and organic artefacts.
- To develop research based cultural resource management tools for locating sites at risk.
- To develop strategies for dealing with threatened sites in Greenland.

The scientific relevance of the project is linked to the lack of knowledge regarding the coupling between climate, site stability and soil/artefact degradation. Through detailed site investigations and degradation experiments, REMAINS will provide the fundamental knowledge needed to quantify the short and long-term net effects of climate change on the preservation of archaeological sites and artefacts. The obtained results will be combined with regional projections of environmental changes in a desk-based Geographical Information System (GIS) model that can be used to perform a regional assessment of threats to archaeological sites. At the end of the project this GIS model will constitute a

new management tool that can assist the Greenland National Museum to pin-point the most vulnerable areas and thereby help to prioritize and optimize future archaeological investigations. In this manner, the results of REMAINS will not only be of value to the scientific community but also benefit the general management of archaeological sites in Greenland.

The REMAINS concept

REMAINS is a co-operation between The National Museum of Denmark (NM), The Greenland National Museum and Archives (NKA) and Center for Permafrost (CENPERM) at University of Copenhagen and is built on the experiences of several previous collaborative projects, including a pilot project of REMAINS in 2012 (Knudsen *et al.*, 2014). The project group consists of a team of experienced researchers, young researchers and students. All people associated with the project are listed on page 25.

The project focuses on the Nuuk region in South West Greenland, which is the part of Greenland with the highest density and variety of archaeological sites and where the effects of climatic change are already visible. Furthermore, this is the most accessible part of Greenland providing clear advantages, both in relation to logistical challenges and the involvement of the local population and students which are considered important parts of project.

The project is structured in two integrated Work Packages (WPs):

- **Work package 1:** Studies of site and artefact degradation
- **Work package 2:** Regional risk assessment and development of guidelines

The project will begin 1 March 2016 and run for three years.

Background and state of the art

Climate change related processes are leading to an accelerated destruction of archaeological sites in the Arctic, and all the information they contain (Blankholm, 2009). Changes in air temperatures cause permafrost thaw (Hollesen *et al.*, 2011; Schaefer *et al.*, 2011) that may expose hitherto well preserved archaeological layers and artefacts to accelerated chemical and physical degradation (Hollesen *et al.*, 2015). Warmer winters and increasingly favourable growing season conditions lead to more and

denser vegetation with deeper roots (Epstein *et al.*, 2012; Henry *et al.*, 2012) that causes physical damage to buried artefacts and destruction of site layering/stratigraphy. Changes in precipitation affect the water balance and thereby have a strong influence on the amounts of oxygen that diffuses into the cultural layers. Finally rising sea level and storm surge impacts increase coastal erosion rates and represent a great threat for the many archaeological sites located close to the sea.

Since 2009 the National Museums' of Denmark and Greenland and the University of Copenhagen have collaborated in order to investigate how climate change affects archaeological sites in Greenland. Research on the Qajaa kitchen midden in the Disco Bay area in Greenland (seen on the front page) documents that wooden artefacts preserved for more than 4,000 years in the permafrost but exposed to summer thaw following an archaeological excavation in 1982, are markedly degraded (Matthiesen *et al.*, 2013). Laboratory experiments show that the oxic (in the presence of oxygen) decay of both organic archaeological soil and wooden artefacts is temperature-dependent with rates increasing 10-15% for each one degree of warming (Hollesen *et al.*, 2012; Matthiesen *et al.*, 2013). The decay of the organic and nutrient rich archaeological material produces great amounts of heat which may act as an important positive-feedback mechanism that further enhances permafrost thawing and the speed at which organic materials are lost (Elberling *et al.*, 2011; Hollesen *et al.*, 2015). The measured decay rates have been combined with on-site monitoring data in a numerical computer model in order to assess the future thawing and decay of the kitchen midden (Hollesen *et al.*, 2015). The model results show that great parts of the midden may be thawed within the next century with significant negative effect on the preservation conditions. The results suggest a critical shift from a first phase of relatively slow permafrost thaw, driven by climate changes and low heat production, to a second phase of accelerated permafrost thaw when water is drained and increasing oxygen availability markedly triggers a higher internal heat production. If this tipping point is reached the heat production can accelerate the decomposition processes and cause the impact of climate change to be significantly enhanced. A preliminary decay study on samples from two sites in the Nuuk region (collected during the pilot project) indicates that archaeological sites without permafrost may be highly vulnerable to changes in temperature and soil moisture and also hold the capacity to produce significant amounts of heat. This suggests that organic archaeological materials may be at great risk at archaeological sites all over Greenland and consequently calls for further investigations.

To date it is mainly the decay of archaeological soil that has been studied in Greenland. Consequently, very little is known about the degradation of other types of organic archaeological materials. The research at Qajaa revealed that the absence of specific lignin-degrading fungus (white rot and brown rot) have helped the preservation of wood (Matthiesen *et al.*, 2013). These microorganisms have been identified in several buildings and constructions in the Arctic (Mattsson 2010). Climate change is expected to improve growth conditions for white rot and brown rot and may therefore result in a substantial and fast decay to the massive amount of archaeological wooden objects found in Greenland. Furthermore, the degradation of the many buried bones found in the Greenlandic kitchen middens needs to be studied. Bones recovered from archaeological sites contain significant amounts of information that can be used within archaeological science and other biomolecular studies, including dating (e.g. radiocarbon, amino acid racemization, age at death), genetic and dietary studies (Child, 1995).

In 2012 a pilot project of REMAINS was carried out in the Nuuk region to find suitable study sites and get a broader overview of the different climate induced threats to archaeological sites. A dramatic increase in the natural vegetation cover was observed at several in-land sites with signs of roots causing physical damage to ruins and buried artefacts and disturbing the site stratigraphy (Knudsen *et al.*, 2014). Human induced changes in vegetation were also observed as small allotments had been established at some of the nutrient rich archaeological sites. The pilot project also demonstrated that in the Nuuk region the threat from coastal erosion was limited as the coast mostly consists of solid rock. Instead fluvial erosion by melt water and soil movement due to freeze-thaw processes was much more actively causing physical damage to sites.

In the light of these results and the fact that global climate models predict an air temperature increase of 3-7°C within the next century (IPCC, 2013) it is urgent that we act now in order to document and manage the archaeological remains in Greenland. Improved knowledge on the nature of feedback mechanisms and processes controlling preservation conditions are needed in order to quantify the rate at which the different threats are causing degradation. At the moment it is impossible to predict where and when preservation conditions may worsen. Individual point/site observations of the net effect of climate change cannot be carried out at every site. Thus, methods to upscale from local to regional scale are needed in order for the Greenland National Museum to safeguard and optimally manage Greenland's archaeological heritage.

The impact of climate change on cultural heritage sites is not only a problem in Greenland. In May 2014, the National Museums of Denmark and Greenland hosted the ICOMOS International Polar Heritage Committee Conference - The future of Polar Heritage (IPHC, 2014). One of the main statements of the conference was that cultural heritage sites are degrading all over the Arctic region due to climate change and that very little has currently been done to address this fact. It was concluded at the conference that adequate strategies and operational frameworks for coping with the situation need to be developed or the result will be that too little is done too late.

Detailed research plan

Study areas and sites

In Greenland the climatic conditions may vary significantly within relatively small areas depending on the distance to the ice sheet and the sea (Figure 1). Furthermore, local climatic conditions may have a significant influence on both the surface conditions (vegetation and snow cover) and on the conditions in the soil environment (soil temperatures and water content). Thus, selecting representative sites is essential to provide a reliable and robust understanding of the interactions between climate and preservation conditions.

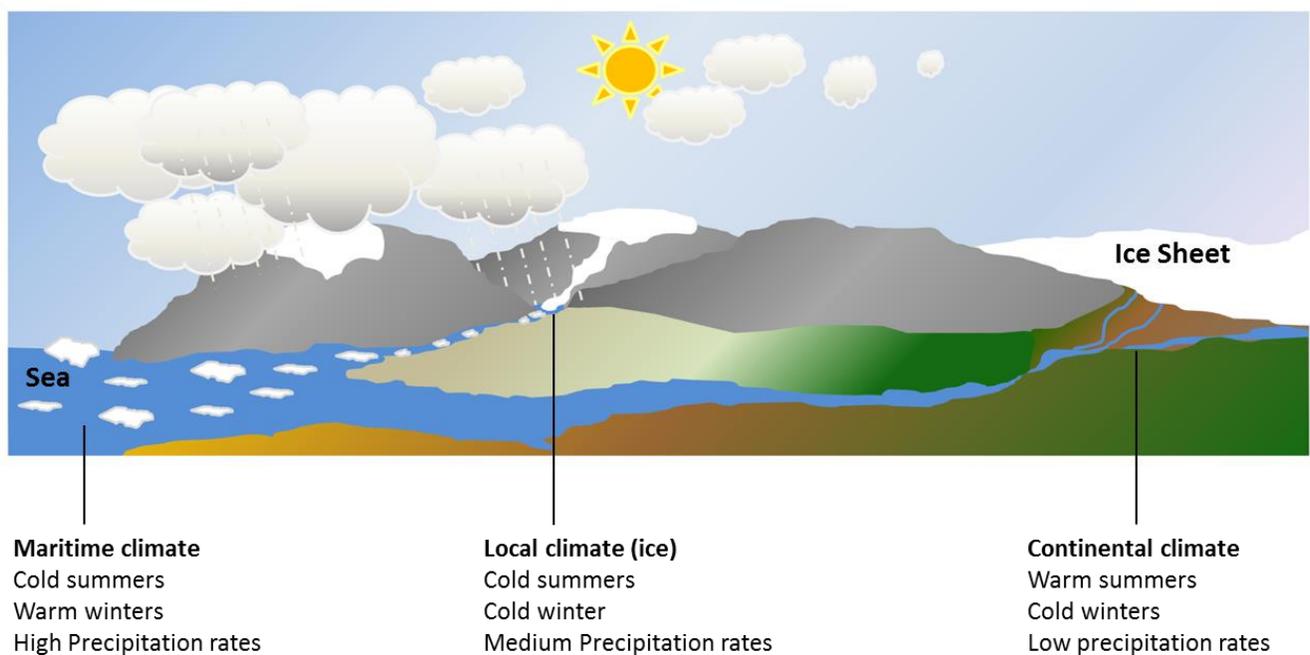


Figure 1: The figure highlights the significant gradients found in the Nuuk region: from maritime to continental climate and from lowlands to highlands.

REMAINS focuses on archaeological sites in the Nuuk region in South West Greenland, which is the part of Greenland with the highest density and variety of archaeological sites and where the effects of climate change are already visible (Figure 2). Even though the Nuuk region only constitutes a small part of Greenland, the climatic conditions vary significantly within the region due to a strong climatic gradient between the sea in the West and the ice sheet located approx. 100 km inland to the East. Thereby, it will be possible to study very different conditions - both at the surface (vegetation and snow cover) as well as in the soil (soil temperatures and water content). This approach will ensure that the knowledge and methods developed during the project will provide a good and robust foundation for future projects to extend the climate risk investigations of cultural heritage sites to other parts of Greenland or other Arctic areas.

The project will collect samples and information on preservation conditions from at least 10 sites in the Nuuk region (Figure 2). The sites visited will be located along a **West/East climatic transect** from the Low Arctic maritime coastal areas to the Low/Sub Arctic continental inner fiords. The sites will represent all of the main cultures that have lived in Greenland (Inuit hunters, Norse farmers, and Preinuit cultures) and many typical site environments representative of other areas in Greenland. Extensive fieldwork will be carried out at the three sites Kangeq, Ummannaq and Kilaarsafik in order to perform environmental monitoring and detailed *in-situ* investigations of physical and biogeochemical processes and to allow for data collection and sampling of materials. Data and samples from Igaliku in South Greenland and from Qajaa in the Disko Bay area will be included in the project in order to widen the validity of the obtained results. This data is freely available from other ongoing research activities at the partner institutions.



Figure 2: The map shows the study region forming a **West/East climatic transect** from the Low Arctic maritime coastal areas to the Low/Sub Arctic continental inner fiords. Sites will be visited in the region and detailed studies are carried out at three key sites. The **Sandnes/Kilaarsarfik** site in the Ameralik south-east of Nuuk is one of three church farms identified in the Norse Western Settlement and was the main chieftain's seats in the area, functioning both as an economic and religious center. Because of the excellent preservation it constitutes one of the archaeological cornerstones in the understanding of Norse architecture and economic development (Russell, 1936; McGovern, 1996); The **Uummannaq** site is an Inuit settlement and Moravian mission (1861-1951) overlaying remains from Pre-Inuit cultures, Saqqaq and Dorset (Toft, 2011). Previous visits show that the site is threatened by erosion (Gulløv *et al.*, 1983; Toft & Gulløv, 2011). Its proximity to Nuuk makes it a good site for field schools and on-site dissemination; **Kangeq** is situated at the outer coast comprising up to two-meter thick kitchen middens with up to 4000 years old cultural layers which currently is being eroded by the sea. The site was partly excavated in 1968, where permafrost was observed (Gulløv, 1997). In addition data and samples are used from: The **Qajaa** site is a 3m thick permafrozen kitchen midden with well-preserved remains from the Saqqaq, Dorset and Thule cultures, and is part of the UNESCO World Heritage Site Ilulissat Icefjord (Meldgaard, 1983; Elberling, 2011); **Igaliku** was the residence of the Norse bishop in Greenland (Arneborg, 2000). The cultural layers of the site are now threatened by modern farming. It is on the tentative list for UNESCO World Heritage sites.

Work package 1: Studies of sites and artefact degradation

Introduction

Some of the most important factors influencing the preservation of archaeological sites and materials therein will be investigated in order to understand the effect of climatic changes on the preservation of archaeological remains and to predict future preservation conditions. The purpose of WP 1 is to investigate processes that affect/control the preservation of sites and the decay of buried artefacts. The results of WP1 are essential for interpreting the effect of environmental changes predicted by the regional modeling in WP 2.

Documenting the history of the key sites is a prerequisite for understanding their current state of preservation. Site formation processes and recent changes will be identified by studying reports from previous archaeological surveys and by using historical photos. Small archaeological excavations (test profiles) will be made at each of the key sites in order to evaluate the present state of preservation and to collect soil samples and artefacts to be used in decay studies. The current preservation conditions will be evaluated at each site and potential threats will be identified. This will be achieved through field investigations of erosion, vegetation cover, root penetration and measurements of depth to permafrost, soil water content, soil oxygen content, soil porosity and soil chemistry. Environmental monitoring will be established at each key site in order to understand the present environment and to study seasonal and year to year variations. The monitoring will include meteorological conditions, snow cover, vegetation cover, soil temperatures and water contents. The data will be used to study site/material degradation and the gained know-how will be used to develop a strategy for future environmental monitoring of selected sites.

Main objectives

- To develop a field protocol for site description and risk assessment
- To study degradation processes on a site specific scale
- To study degradation of specific organic materials
- To develop interpretative tools for estimating local degradation from regional climate data

Work package tasks

Task 1.1 Developing a protocol for site description and risk assessment

REMAINS will entail visits to a number of sites. To secure that the gathered data is comparable between sites and over time it is necessary to develop a protocol for site description and sampling. A standard site description form has been used at NKA for several years, but it needs to be updated and expanded with systematic descriptions of state of preservation and threats to the continued preservation. The new protocol will allow for a preliminary risk assessment to be made on-site even during short visits. The protocol will also set standards for high precision GPS measurements and for photo documentation of sites. The protocol will be developed at the beginning of the project, based on the existing experiences from the REMAINS pilot project in 2012, and on experiences from other studies (Dawson, 2008; English Heritage, 2011).

Task 1.2 Document history and recent degradation of sites

Site formation processes and recent changes at all field sites will be identified based on literature search and compilation of existing published reports from previous archaeological surveys. Furthermore, satellite images and historical photos will be used to assess changes in vegetation, shoreline positions and erosion events at the sites.

Task 1.3 Assessment of threats to sites

The current preservation conditions will be evaluated at each site and potential threats will be identified using the protocol developed in task 1.1. At each key site detailed field investigation of erosion, vegetation cover, root penetration and measurements of environmental conditions will be performed. Detailed visual inspections at the key sites will be used to identify/document signs of coastal erosion, fluvial erosion by melt water and para-glacial erosion processes like soil cryoturbation and solifluction (see Kroon *et al.*, 2010). At each of the key sites a detailed mapping of the area will be made using high precision GPS and low altitude high-resolution aerial photography's will be produced using unmanned aerial vehicles (UAV/Drones). The current site morphology will be compared with the

historical documentation from task 1.2 to identify changes in site morphology and to detect recent erosion events.

The type of vegetation will be registered for all sites. The vegetation cover will be mapped and evaluated at each of the key sites (vegetation type and density). Historical photos from task 1.2 will be used to identify if there has been a recent shift in the vegetation cover. The root penetration will be studied for the most important vegetation types in connection to small excavations at the key sites. The effect from the roots on archaeological materials will be studied microscopically on sampled material. At two sites the recent plant growth (above and below ground) will be studied in more detail using dendrochronology (Hollesen *et al.*, 2015). In this experiment plants will be collected at the archaeological sites and in the surrounding areas. Thereby it will be possible to investigate the difference in growth potential between natural soils and archaeological deposits.

The current environmental conditions within the soil environments will be investigated through on-site measurements of oxygen content, soil temperatures, soil water contents, pH, thermal conductivity, and heat capacity. Environmental monitoring will be established in order to understand the present environment and to study seasonal and year to year variations. The data will also be used to study site/material degradation. Monitoring will include: weather stations, measurement of soil temperatures and soil water contents, and automatic cameras for monitoring snow and vegetation cover. Monitoring has already been initiated at the key sites of Kilaarsafik (2012) and Kangeq (2012) although supplemental equipment will be needed (Figure 3). During the monitoring period each site will be visited 2-3 times to download data and maintain/replace equipment.



Figure 3: A logger station has been installed at the Kilaarsafik key site since 2012.

The thermal/hydrological regimes of the key study sites will be investigated through measurements of meteorological conditions and laboratory studies of soil physical properties as input in a simple analytical model and an advanced numerical model (“The CoupModel”), which has previously been successfully used to model conditions within an archaeological kitchen midden (Hollesen *et al.*, 2015). The models will be calibrated and validated using measured values of soil temperatures and soil water contents. The results from the two types of models will be compared to evaluate the level of details needed to describe internal conditions.

The validated model setups will be used to predict the effect of changes in air temperature, precipitation and snow cover on soil temperatures and soil water contents. The model results will be linked with measured decay rates and heat production rates to evaluate future preservation conditions and furthermore used to test the result from the regional model in WP 2.

Task 1.4 Assessing the deterioration of organic archaeological remains

The low temperatures and high soil water contents found in Greenland have provided unique conditions for organic materials such as wood, bone, textile, skin and plant remains to be preserved for millennia. However, the current increase in air temperatures cause longer periods of ground thawing and altered precipitation patterns, which may result in drying of near-surface layers and increasing oxygen availability. Both factors could accelerate the deterioration of buried organic materials (Hollesen *et al.*, 2012). In addition, a higher frequency of freeze-thaw cycles could potentially lead to a relatively fast physical degradation of organic artefacts. The absence of specific lignin-degrading fungus (white rot and brown rot) have until now helped the preservation of wood at the permafrozen Qajaa key site (Matthiesen *et al.*, 2013) and in other cold regions (Blanchette *et al.*, 2010). If these microorganisms spread throughout Greenland in a future warmer climate they may cause a substantial decay to preserved wood. This task aims to advance our basic understanding of how changes in soil temperature and water content influence the decay of archaeological soil, wood and bone from the key sites. This will be achieved through the following steps:

Decay of the soil bulk material and archaeological wood and bone will be investigated through a combination of laboratory experiments and *in-situ* experiments. The current state of preservation of the material and presence/absence of different types of wood degrading fungi will be evaluated through microscopy studies and density measurements (Jans, 2005; Gregory & Jensen, 2006), Material specific decay rates will be investigated by measuring CO₂ production and O₂ consumption at different temperatures and water contents, based on the assumption that the decay of organic material in the presence of oxygen produce CO₂.

Material specific heat production rates will be measured using microcalorimetry at different temperatures and water contents. These data are a proxy for decay and will give new insight to the effect of heat production as a positive feedback mechanism for soil thaw.

Samples of modern wood and fresh bone were buried at the study sites of Kangeq and Kilarsaarfik during the pilot project in 2012. The samples were buried at different depths and in areas of different solar exposure (North/South) and soil temperature and water content has been monitored since. These samples will be collected and their state of preservation will be investigated in order to document decay patterns. The observed *In-situ* decay will be compared to results from the laboratory and provide information on how site-specific micro climate and regional climatic differences between

sites affect preservation conditions. Furthermore the collected bones will be used to investigate the temperature-dependent breakdown of DNA using a thermoblock in the range from -5 to +25°C.

Work package 2: Regional risk assessment and development of guidelines

Introduction

Assessments of threats to archaeological sites in the Nuuk region will be made using a desk-based environmental model that analyses existing digital data-sets in a dynamic GIS environment (ArcGIS 10.3). The GIS model include the sensitivity for coastal erosion, fluvial erosion, periglacial processes, changes in vegetation, soil temperatures and soil moisture content (Westley *et al.*, 2011; Sharples, 2006; Kroon *et al.*, 2010). The GIS model will be linked with an updated version of the Heritage Database at NKA to locate vulnerable hotspots and to make risk assessments, which will be used as a tool to prioritize future surveys and excavations. The impact of threats will be quantified and the likely degree, pattern and rates at which climate change may impact particular areas/sites estimated.

Assessments will be made for current conditions and a selection of future climate scenarios according to HIRHAM and data from DMI (2013-2100). The results will be tested/validated using the collected data from the key sites and the detailed process modelling in WP 1 (task 1.3). The REMAINS concept of studying sites located along an East-West transect secure a robust validation process because sites located within very contrasting environments will be included (ex. from no to sporadic permafrost or from sparse vegetation to meter high willow).

Main objectives

- To develop a regional GIS model for assessing the vulnerability of archaeological sites in the Nuuk region under current and future climatic conditions.
- To update the Heritage Database at NKA with the information collected during REMAINS and link it within the GIS model.

Work package tasks

Task 2.1 Management of input data

The management of input data is especially focused on obtaining and organizing existing data sets.

Base maps

The regional assessment model covering the Nuuk area will be based on existing quality digital maps for Greenland which are available from CENPERM. These maps are subject to scale-limitations (1:25000), which limits the resolution at which areas potentially vulnerable to climate change can be identified. Therefore, when necessary, high resolution satellite images (Quick Bird/ WorldView2 satellite /GeoEye-1), orthophotos and existing Digital Terrain Models will be used to improve the spatial and temporal resolution. This will be done using a combination of new images and images that are already available to the project from CENPERM.

Coastal erosion and future sea level rise

The vulnerability of shorelines to coastal erosion will be classified in two ways. The coastal types and their sedimentary features are identified and classified on the base maps (Kroon *et al.*, 2010). The intensity of coastal processes, especially the potential impact of wave energy on different parts of the shore will be evaluated by investigating the fetch of waves on open water. Sea ice plays an important part in this relation as sea ice prevents the waves from building up. Therefore, predictions of current and future sea ice cover from the databases of DMI and NOAA will be included. The current sea-ice cover and its seasonal and yearly variability will be derived from existing sea-ice observations at DMI (CENPERM/DMI). Predictions of the sea level rise (SLR) in Greenland are made by DMI and are available through CENPERM. These predictions will be adjusted with predictions of isostatic uplift/subsidence from DTU-Space (Khan *et al.*, 2010). This is necessary because parts of Greenland are undergoing large glacio-isostatic adjustments. The adjusted predictions will be mapped by flooding a digital elevation model (DEM). This is an upward adjustment of the zero contours with the predicted values of SLR. The comparison of the pre- and post-flooding shorelines indicates the potential amount of coastal retreat. The rate of inundation is dependent on many factors like the intensity and duration of the flooding and the local topography. Low-sloping relatively small areas will be more easily flooded than steeper areas, and topographic slope angles will be used to modify predictions of coastal retreat.

Fluvial and periglacial processes

The impact of small creeks and rivers on archaeological sites can be positive or negative. An increase of melt-water run-off from the glaciers due to warming could increase sediment transport through the rivers to the coastal areas and have a protective impact on the stability of sites. Conversely, local fluvial adjustments, like lobe- or channel-shifting in the lower parts of streams on deltas or alluvial fans might locally erode sites (e.g. Kroon *et al.*, 2011). The fluvial systems and their impact will be included in the assessments by localizing potential local sources of sediments (mouth of rivers and creeks) on the base maps. Periglacial processes alter the landscape in Western Greenland and may have an impact on the archaeological sites. Slow processes like solifluction may modify the stratigraphy of cultural layers and in some cases form lobes that ultimately cover sites. Faster processes like permafrost thaw can destabilize sedimentary cliffs and increase the erosion rates. Areas prone to solifluction (slopes) as well as sedimentary cliffs will be identified on the base maps in order to predict the vulnerability of the landscape to periglacial erosion processes.

Changes in the soil environment

The climatic data used in the GIS model is output data from the regional climate model (RCM) HIRHAM5 which is available to the project through CENPERMs cooperation with DMI. HIRHAM5 provides temperature and precipitation data in a ground resolution of 5x5 km for five 10-year periods (1990-1999, 2046-2055, 2056-2065, 2080-2089 & 2090-99). The climatic data for each 25 km² grid cell will be adjusted according to the topography (lapse rate adjustments) and then used as input in the numerical model CryoGRID 1.0 to predict soil temperatures for the whole region at 30x30 m ground resolution (Gisnås *et al.*, 2013). The definition of soil types in the regional assessment will be based on soil and geological maps and the soil moisture levels will be classified according to vegetation types and terrain analyses. Normalized Difference Vegetation Index (NDVI) (Rouse *et al.*, 1974) will be used to estimate the current surface greenness and soil moisture content based on a relationship between NDVI and phytomass (Raynolds *et al.*, 2012). The future vegetation measured as biomass will be estimated from a relationship between the mean July temperature (MJT) and time integrated NDVI (Raynolds *et al.*, 2006; Westergaard-Nielsen *et al.*, 2015). In figure 4 an example is given of how this method has been used to estimate the current phytomass in the Nuuk area.

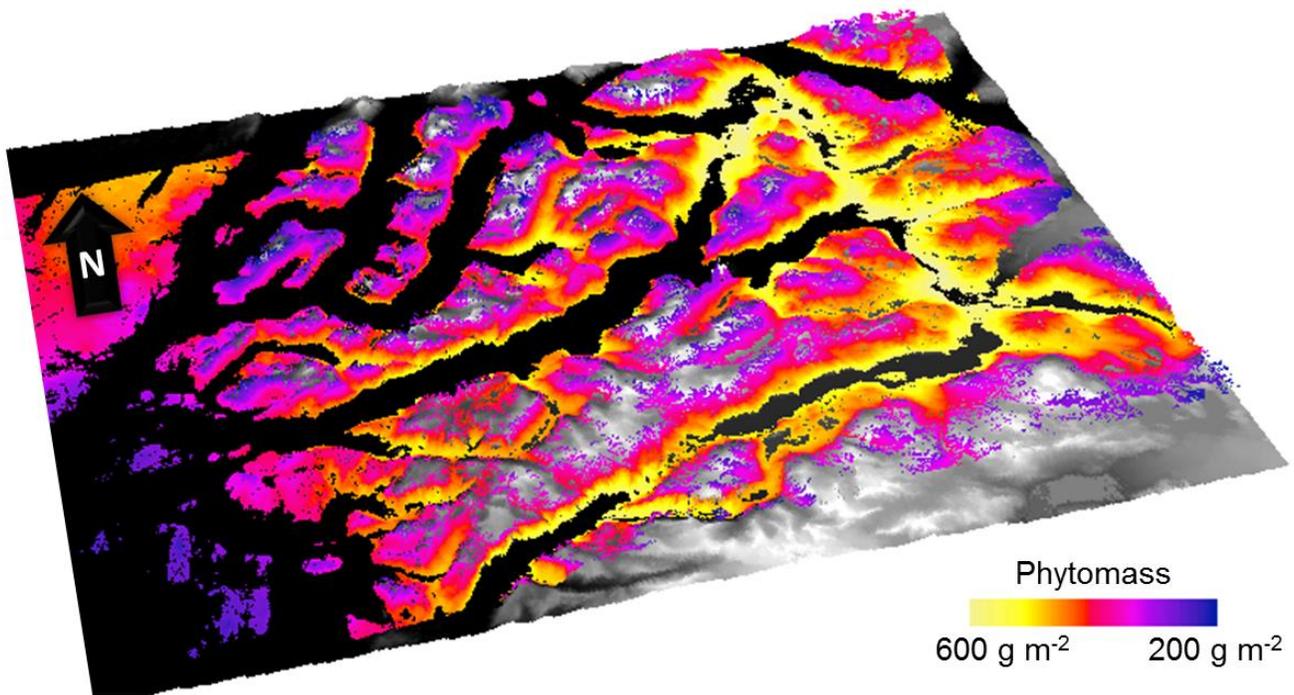


Figure 4: Downscaled satellite-based estimate of phytomass in the Nuuk area, 2014 (provided by Westergaard-Nielsen)

Task 2.2 Regional assessment of threats to preservation conditions

The data gathered in task 4.1 will be used to assess and map current and future erosion rates, changes in biomass and vegetation composition, soil temperatures and soil moisture contents. The spatial trends of current conditions will be validated using the regional and site specific data collected in WP 1 and the predictions of future conditions will be tested using the detailed model results from WP 1 (task 1.3). The results will be linked with the degradation studies task 1.4 in order to evaluate how the predicted environmental changes may affect the preservation of the archaeological materials/sites. The final result will be regional maps where the most vulnerable locations will be marked as hot-spots.

Task 2.3 Linking the GIS model with an updated version of the Heritage Database at NKA

The existing Heritage Database at NKA includes 6500 sites. The database will be updated to allow the site specific data from the preservation protocol (WP 1) to be implemented. The database will be linked with the assessments of threats from task 2.2 in a GIS environment to make regional risk assessments and evaluate/categorize the vulnerability of all the registered archaeological sites. This, combined with the available information on archaeological and historical significance, will help The

Greenland National Museum to prioritize future surveys, monitoring programs and excavations based upon possible environmental threats due to climatic changes.

Task 2.4 Development of guidelines for future monitoring and management of archaeological sites

Monitoring and managing archaeological sites in Greenland is difficult due to the large distances, expensive logistics, and a short field season. This must be taken into account when developing guidelines for monitoring and management. Based on the developed standard protocol (WP 1) and the experience obtained during REMAINS a generic guideline will be produced that can be used by archaeologists and locals for characterising the state of preservation and possible threats to archaeological sites. Furthermore, this guideline will be used in future archaeological surveys in Greenland, and the results will be incorporated in the existing database on cultural heritage sites at NKA.

The Greenland National Museum does not have funding and capacity to excavate or protect all sites that are threatened by climate change. Nevertheless, if the regional risk assessment or site specific monitoring shows that a site is under active degradation, it is necessary to have procedures that can be implemented to ensure its optimal management. A standardized procedure will be developed to prioritize rescue excavations and externally funded research excavation projects in Greenland. Active mitigation and protection of sites threatened by natural changes will only seldom be possible and is beyond the scope of the current REMAINS application.

REMAINS associated persons

NM – The National Museum of Denmark

Jørgen Hollesen, PhD and senior researcher and 20% associated to Center for permafrost (CENPERM). His expertise is in geochemistry, permafrost processes and environmental impact modelling and he has experience from research projects in Svalbard and Greenland.

Henning Matthiesen, PhD and senior researcher, has fourteen years working experience with in-situ preservation of archaeological remains in different environments.

David Gregory, PhD, Research Professor, 23 years work experience with degradation of archaeological materials and in situ preservation of archaeological sites in land and marine environments.

Nanna Bierregaard Pedersen, PhD and postdoc/conservator has research expertise within wood science, microbiological decay processes, and micro-spectroscopic and dendrochronological measurements. Her main focus is micro-chemical and ultrastructural material characterisation of archaeological wood. In July 2015 Nanna will start a two year Post Doc funded by Carlsbergfondet studying wood degrading fungi in Greenland. Her project will be closely linked to REMAINS.

NM/ Centre for Geogenetics, University of Copenhagen

Anne Marie Eriksen, PhD student and has an MSc in Conservation Science and Restoration. She has worked with waterlogged organic material and bio-deterioration and degradation of marine cultural heritage. She has also worked with genetics and DNA analyses in different aspects of conservation research. In June 2015 Anne Marie will start her PhD (funded by Danish Council For Independent Research) studying the degradation of archaeological bones (including samples from Greenland).

Centre for Geogenetics, University of Copenhagen

Morten Allentoft, PhD and Associate Professor, specialises in ancient DNA research with the main focus of uncovering past population histories. However, of direct relevance to the proposed project,

Morten also has extensive experience in estimating DNA decay rates based on fragmentation patterns in ancient genomic data.

NKA - The Greenland National Museum and Archives

Bo Albrechtsen, Deputy director at NKA

Mikkel Myrup, BA in social and cultural science and curator at NKA, has ten years experience with GIS handling of archaeological sites.

NB: NKA is currently seeking two new archaeologists (application deadline 15 may 2015). Both archaeologists will be part of REMAINS.

CENPERM - Center for Permafrost Dynamics in Greenland, University of Copenhagen

Bo Elberling, PhD and Dr. Scient, Professor at Department of Geosciences and Natural Resource Management, University of Copenhagen & director of CENPERM, Center for Permafrost, a center of Excellence funded by The Danish National Research Foundation (2012-2018). His expertise is environmental biogeochemistry in general with a special interest in permafrost-affected aspects.

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