Evaluating Viking eco-cultural niche variability between the Medieval Climate Optimum and the Little Ice Age: a feasibility study

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Abstract

In the northern Atlantic, Norse agricultural and pastoral practices flourished from the 9th to the 13th century, after which Viking occupation of these regions abruptly declined and eventually disappeared towards the beginning of the 15th century. In this study, in order to evaluate the possible role of climatic variability on Viking settlement of these regions, we used the Genetic Algorithm for Rule-Set Prediction (GARP) to reconstruct the Viking eco-cultural niches during the end of the Medieval Warm Period (MWP) and the beginning of the Little Ice Age (LIA).These reconstructions demonstrate that the application of ECNM to this time period and Viking settlement dynamics is both feasible and relevant. Furthermore, preliminary results suggest that climate and environmental change played prominent roles in the abandonment of Greenland by Viking populations and are consistent with available historical accounts. Our results encourage us pursue further analyses with the use of more precise paleoclimatic and archaeological data in order to better understand the role of environmental change in the disappearance of Viking culture from regions of the northern Atlantic.

Keywords*:* *Norse settlement; Greenland; Eco-cultural niche modeling; Little ice age.*

1. Introduction

Eco-cultural niche modeling (ECNM; Banks *et al.*, 2006; Banks *et al.*, 2008a) is a heuristic approach that has been used to evaluate how prehistoric cultures and their distributions may be affected by abrupt climate, and resulting environmental, change. The objective of this study is to test whether this approach is feasible and relevant for historical populations. ECNM integrates archaeological, chronological, and environmental datasets, through the use of biocomputational architectures (Peterson *et al.*, 2011), to reconstruct the ecological niche occupied by a past, culturally-cohesive human population. This eco-cultural niche represents the range of environmental conditions within which a given culture can persist without having to immigrate (Banks *et al*., 2008a). To date, ECNM has been used to identify potential human ranges and explore the role of climatic variability on cultural geography and lithic technology during the Last Glacial Maximum (Banks *et al.*, 2009; Banks *et al.*, 2011), as well as to evaluate the role of climate in the disappearance of Neanderthals during the latter stages of Marine Isotope Stage 3 (Banks *et al*., 2008b).

In this feasibility study, we employ ECNM methods to assess the possible impact of climatic variability on the Norse settlement of Greenland. We opt to focus on Viking populations in this sub-arctic region because most authors suggest that the collapse of Viking settlements could be due to climatic change (Dansgaard *et al*., 1975; McGovern, 1991; Stuiver *et al*., 1995; Barlow *et al*., 1997; Kuijpers *et al.*, 1999; Patterson *et al*., 2010; D'Andrea *et al.,* 2011) while others, without systematically excluding climate as a factor, argue that political, economic, and cultural factors were the principal causes (Dugmore *et al.,* 2005, 2012; McGovern, 2007; Massa, 2010).

1.1. Norse settlement

Norse populations populated Iceland around AD 870, and a little over a century later, historical accounts indicate that Erik the Red and his father Thorvald Asvaldsson left Iceland because they had been implicated in a homicide (Gad, 1970; Karlsson 2000). In AD 985, they settled in a land named Greenland which was previously discovered by the explorer Gunnbjörn Ulfsson sometime between AD 876–932 and named Greenland by Erik Thorvaldsson (known as Erik the Red) in order to distinguish it from Iceland, as well as to attract settlers (Massa, 2010). Less than two hundred years later, the population of Greenland had grown to several thousand inhabitants due to climate conditions that favored Viking agricultural and pastoral practices (McGovern, 1991). Viking populations were primarily distributed in two regions: the Eastern Settlement and the Western Settlement (Figure 1). Based on ecclesiastic records, we know that the Western settlement had been abandoned by AD 1350, and the last record that documents a Norse presence Greenland is a letter dated AD 1409, which announces a marriage that took place in AD 1408 (Gad, 1970).

Figure 1: Map of the northern Atlantic showing the locations of the archaeological sites used to reconstruct eco-cultural niches. Both circles and squares represent the "first settlement" while circles alone represent the "second settlement".

1.2. Norse economy

Studies and simulations of farming economies that characterized the Viking era in Iceland suggest that the Norse economy required an adapted land management strategy that was based in part on specific suites of coastal environmental attributes and close economic and social connections between farmsteads (Adderley *et al*, 2008). It is reasonable to assume that the same held true for farmsteads in Greenland (Keller, 1991), and cultural and economic connections between Iceland and Greenland were maintained through trade. Populations in Greenland procured Arctic products such as walrus ivory, polar bear skins, and Arctic falcons, which were exchanged for commodities from Iceland such as iron, salt, timber, honey, and dyes.

Norse subsistence was principally based on livestock including cattle, sheep, goats, pigs and horses (Dugmore *et al*, 2012). While they did cultivate barley, corn spurrey (*Spergula arvensis*) and flax (*Linum usitatissimum*) (Fredskild and Humle 1991, Dugmore *et al.* 2012), most agricultural production focused on fodder used to feed cattle during the winter. These agricultural practices required special and adapted equipment (closed fields, channel irrigation, manure fertilization, barns) and practices such as forest clearing (Arneborg, 2005; Adderley and Simpson, 2006; Adderley *et al.*, 2008; Buckland *et al*, 2009; Dugomore *et al.*, 2012; Fredskild, 2012). Norse sagas narrate that settlers in Greenland regularly sailed to Newfoundland in order to obtain timber, and a Norse presence in North America is indicated by archaeological materials recovered from the site of the Anse aux Meadows (Wallace, 1991).

During the early stages of their occupation of Greenland, which occurred during the Medieval Warm Period (MWP), Norse populations practiced agriculture and pastoralism while their neighbors, the Inuits, subsisted on sea resources. Isotopic analyses and zooarchaelogical data indicate that, across all five centuries of their Greenland occupation, Norse populations did progressively adopt Inuit subsistence practices to a minor extent (Arneborg *et al.,* 1999, 2012; McGovern *et al.,* 2006). However, as pointed out by several authors, on the whole, Viking populations did not significantly modify their sedentary, production-based lifestyle, and continued as much as possible their 'cultural intransigence' (Barlow *et al.,* 1997); *i.e*., agrarian production combined with livestock grazing.

1.3. Climatic deterioration and social impacts

Numerous climate records indicate that between AD 1350 and AD 1850 the climate deteriorated, and this period is termed the Little Ice Age (LIA). This severe climatic deterioration disturbed the Norse economy (Dansgaard *et al*., 1975; Dugmore *et al*., 2007), adversely affecting agricultural productivity due to dry winds (Lassen *et al*., 2004) and rising sea levels (Mikkelsen *et al*., 2008). These climatic changes also adversely affected trade since sea ice off southeastern Greenland significantly expanded and made shipping between Iceland and Greenland difficult (Kuijpers, *et al.*, 1999). In addition to the lack of hay to feed cattle and a lack of fresh water due to drought, the disruption of maritime trade routes deprived Greenlanders of products such as iron and timber. These colonies were no longer interconnected, thus preventing the maintenance of the Viking lifestyle in an environment not as clement as that of previous centuries. Furthermore, these populations were affected by disease, piracy, and conflicts with Inuits and other neighboring populations that they called "*Skræling"* (*Grœnlendinga saga* and *Eiriks saga rauða*). All of these factors created a situation in which Norse populations were obliged to either modify their subsistence practices or abandon their Greenland settlements.

2. Materials and methods

To estimate Viking eco-cultural niches, we used the Genetic Algorithm for Rule-Set Prediction (GARP; Stockwell and Peters, 1999). For data inputs, GARP requires the geographic coordinates where the target population has been observed as well as raster GIS data layers that summarize the environmental variables that may be involved in constraining its geographic distribution.

2.1. Archaeological data

We obtained the geographic locations of archaeological sites by scanning and rasterizing maps found in the literature (Krogh,1982; Adderley et al. 2008; McGovern et al., 2007) in Visque: a Google Earth application (http://www.nabohome.org/visque/), or in Google Earth research for the Anse aux Meadows.. Archaeological sites are divided into two datasets to match historical accounts of the settlement of Greenland. The first includes all locations (i.e.: Iceland settlement, Eastern and Western Greenland settlements and the Anse aux medows, n = 544) and is used to represent the Norse distribution during the early period of settlement (MWP and initial LIA). The second dataset represents settlement for the LIA and thus excludes sites in regions that are known to have been abandoned at the beginning of that period (i.e.: some Icelandic sites, Western settlement of Greenland and the Anse aux Meadows, n = 447). Site locations are depicted in Figure 1. Two hundred sites were randomly sampled from each dataset in order to produce each eco-cultural niche prediction. The first sample based on all sites is termed "first settlement", and the second based on remaining sites is identified as "second settlement."

2.2. Environmental data

The GIS layers include climatic and topographic data. Climatic data were obtained from a Global Climate Simulation (Jungclaus *et al.*, 2010: http://www.ncdc.noaa.gov/paleo/metadata/noaa-model-10477.html) and include monthly values for surface solar radiation, surface air temperature at 2 meters above sea level, barometric pressure, and precipitation from AD 800 - 2100. Spatial and temporal computations were processed for each variable. The first step was to increase the spatial resolution for the targeted region (Figure 1), while the second step targeted specific time periods. These operations were performed with the statistical software package R. The spatial treatment was performed using a bilinear method of interpolation, which allows one to obtain a 0.5° resolution from the original 3.5° resolution (*i.e.*, grid cell resolution is refined from 180 km to 26 km on a side). This coarse rounding technique does not take in account microclimates due to local variations but still provides general climatic trends. These operations allowed us to obtain a total of 16 climatic variables (mean values for the months of April, July, October, as well as an annual mean for each of the four climatic parameters) (Table 1). We also included elevation as an environmental variable (Source: Global Multi-resolution Terrain Elevation, Data 2010 - http://eros.usgs.gov/). In order to make its resolution consistent with the climatic layers, we averaged neighbor squares with the same bilinear interpolation method.

2.3 Eco-cultural niche modeling

With these formatted environmental data layers as input, we used GARP to predict the Norse eco-cultural niche for each settlement described above. The first niche prediction used archaeological sites assigned to the “first settlement” and climatic data of the MWP (AD 985–1200). This period represents the height of the Norse settlement of Greenland. The sites assigned to the "second settlement" and the climatic data for the beginning of LIA (AD 1300–1450) were used to reconstruct an eco-cultural niche corresponding to the period characterized by the abandonment of the Western settlement and ultimately the end of the Viking occupation of Greenland. GARP was set-up to produce 200 predictions (100 max iterations for each), and these were summed to produce the final eco-cultural niche predictions.

In order to evaluate potential changes in the geographic distribution of the Norse niche over time and across period of climatic change, we projected the 11th century, "first settlement" eco-cultural niche prediction onto environmental conditions for each century between AD 800–1600.

2.4. Statistics

To evaluate and compare the MWP and LIA eco-cultural niche predictions, we performed a principal component analysis (PCA) using the library Ade4 of the R software.

3. Results

3.1. Geographic expressions of predicted niches: first and second settlements

The eco-cultural niche predictions performed for the MWP and the LIA are shown in Figure 2. For the first settlement, we note that a high probability of presence is predicted for almost all of Iceland and southwestern Greenland (Figure 2A). One also observes that a high-probability of presence is predicted in a small region of southern Labrador, and a lower probability of presence is predicted across a larger area to the north. The second settlement's niche (Figure 2B), shows, relative to the first settlement's niche, a geographical contraction and a disappearance of some areas predicted present in Iceland and Greenland during the MWP. These regions that are lost in the LIA prediction are those that included Greenland's Western Settlement and northern Iceland. Similarly, the regions previously predicted present at a low probability level in northern Labrador are not present in the LIA prediction. However, at the same time, there is a geographic expansion of the Norse eco-cultural niche in southern Labrador. Finally, with respect to the Norse LIA niche, the presence of the predicted niche is only in areas that have known archaeological sites. In other words, the geographic expression of this niche prediction corresponds strictly to areas that are known to have been settled.

3.2. Environmental variable correlations: first and second settlements

Principal Component Analyses performed on the environmental variables for the first and second settlements' predicted niches indicate that there are marked differences between the two (Figure 3). The first two components of the PCA of the first settlement's niche (Figure 3A) represent 75.90 % of the total inertia (component 1 = 51.85 %, component 2 = 24.05 %). The first two axes of the PCA of the second settlement's niche (Figure 3B) explain 68.38 % of the total inertia (component 1 = 46.80 %, component 2 = 21.58 %).

Figure 3C and Figure 3D show there to be large differences between absolute inertia values for many variables between the two niche predictions. With respect to the first component, these differences occur for the annual Equivalent Precipitation Temperature (EPTy), Equivalent Precipitation Temperature for the months of July and October (EPTj, EPTo), and mean sea level barometric pressure in July (MSLPj). For the second component, the differences between the two niche predictions exist for elevation (DEM), Surface Solar Radiation during April and July (SSRa, SSRj), Temperature for April and July (T2Ma, T2Mj), Mean Sea Level Pressure (MSLPy, MSLPa, MSLPj, MSLPo), and Equivalent Precipitation Temperature (EPTy, EPTa, EPTj, EPTo). Further, it should be noted when these variables are not opposed, one of both has almost zero inertia. Finally, variables such as Precipitation (EPTa, EPTj, EPTo, EPTy), Surface Solar Radiation (SSRa, SSRj), and Temperature (T2Ma, T2Mj) show a shift to the left in the second settlement's niche, indicating lower mean values (Figure 4). Thus, the second settlement occupied an ecological niche characterized by a dryer annual climate, lower levels of solar radiation, and colder spring and summer months.

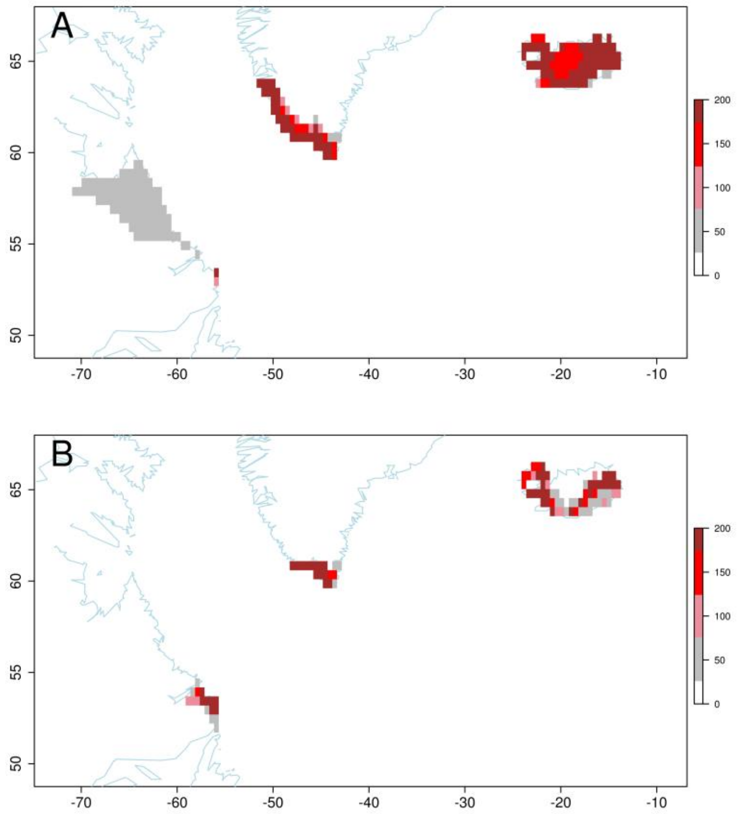

Figure 2: Geographic expressions of the Norse eco-cultural niches predicted for A) the first settlement at the end of the Medieval Warm Period (A.D. 985–1200), and B) the second settlement at the beginning of the Little Ice Age (A.D.1300–1450). These niche reconstructions represent the sum of the 200 produced models and grid square color ranges from grey, to pink, to red, and to brown, or low to high probability: grey = 26–75 models in agreement, pink = 76–125 models in agreement, red = 126-175 models in agreement, and brown = 176-200 models in agreement. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

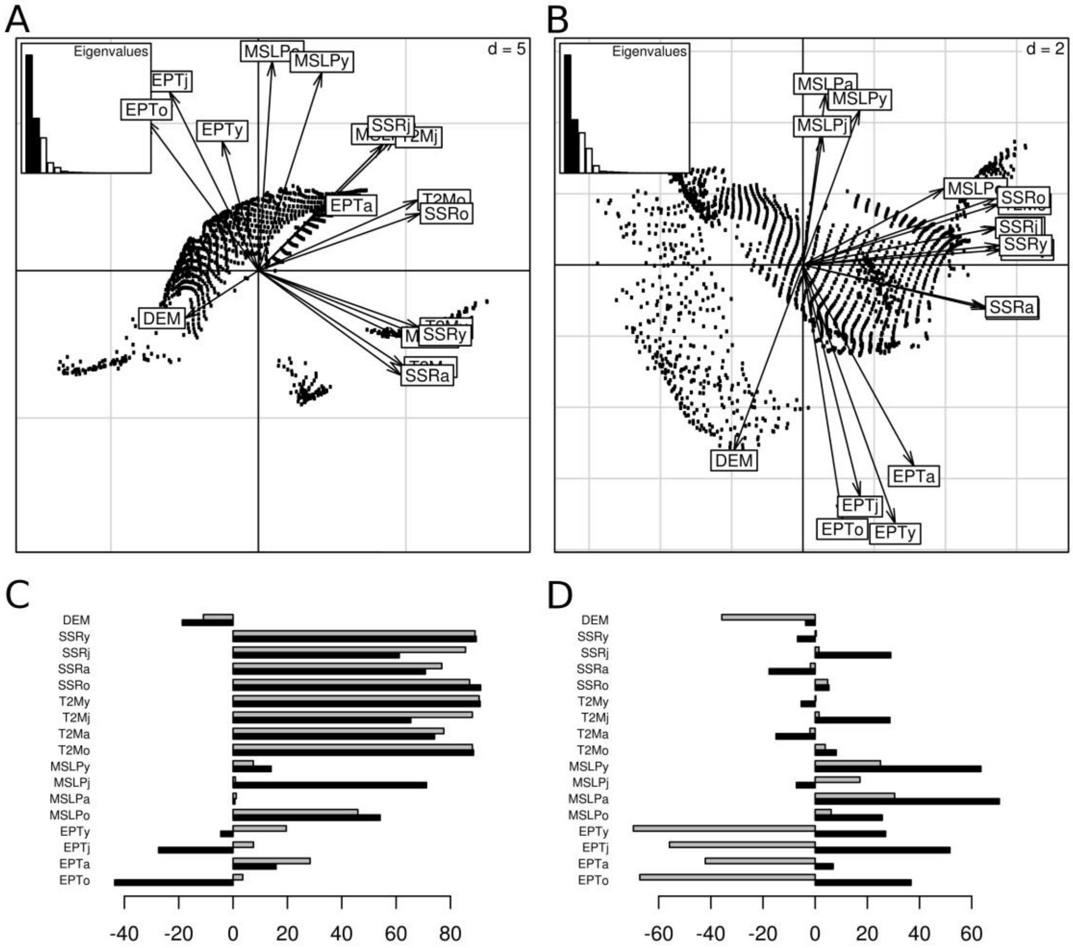

Figure 3: PCA (Principal Component Analysis) of environmental variables of the first and second settlements' predicted eco-cultural niches. Environmental variables are symbolized by arrows, and points depict the predicted presence locations. Black bars represent inertia of the PCA performed on the first settlement's results, while white bars represent depict inertia of the PCA performed on the second settlement's results. (A) Eigen values and factorial map of the first settlement's PCA. (B) Eigen values and factorial map of the second settlement's PCA. (C) Contribution of environmental variables to the first component of each PCA. (D) Contribution of environmental variables to the second component of each PCA. See Table 1 for the list of environmental variables and their abbreviations

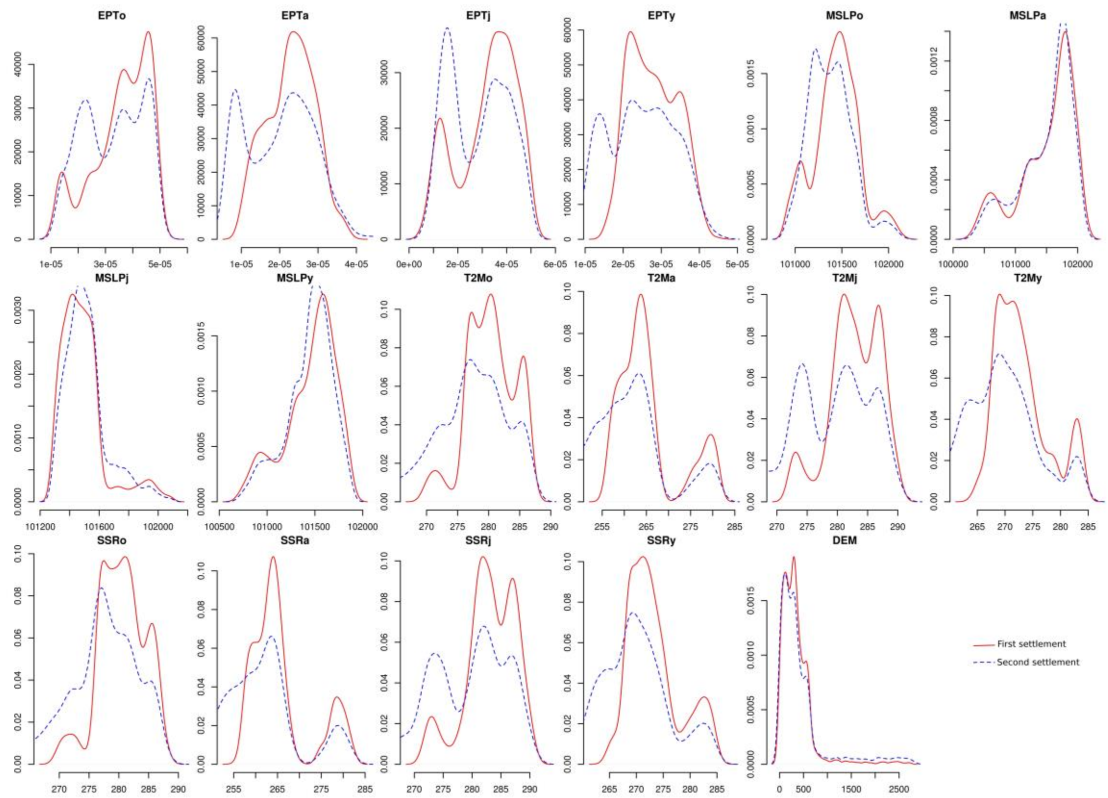

Figure 4: Environmental variable density plots. The density function disperses the mass of the empirical distribution function over a regular grid of at least 512 points. The fast Fourier transform is then used to convolve this approximation with a discrete version of the kernel. Finally, linear approximation is used to evaluate the density at the specified points. See Table 1 for the list of environmental variables and their abbreviations.

3.3. Century-scale variability of the Viking eco-cultural niche

Niche predictions depicted in Figure 5 show the Viking niche predicted for the 11th century (Figure 5C), as well as the projections of this reconstructed niche onto the climatic conditions of other centuries. One notes that the maximum geographic extents of the 11th century prediction and its projections occur during the first four periods (9th–12th centuries). These results correspond closely to the first settlement niche prediction. One also observes that the 10th, 11th and 12th century niche predictions include regions of North America (Northern Labrador / North-Eastern Quebec) but at low levels of probability. On the other hand, the Anse aux Meadows (see location in Figure 1) is never successfully predicted, and only the prediction for the 9th century has a small area, in southeastern Labrador, with a high probability of predicted presence.

The latter four centuries (13th–16th) show a reduction in the geographical area predicted as potentially suitable. There is no longer a presence predicted in North America, and the potential niche in Iceland is relatively small compared to the predictions for the previous centuries (9th-12th). One also observes that in Greenland the geographic extent of the predicted niche decreases. Predictions that have the highest value of presence are located to the south.

4. Discussion

This feasibility study demonstrates that eco-cultural niche modeling methods are effective for evaluating how climatic variability affected the settlement of Greenland by Norse populations, and our results are consistent with available historical accounts (Gad, 1970; Karlsson 2000) and oral histories (*Grœnlendinga saga* and *Eiriks saga rauða*). Furthermore, the Norse niche predictions identify suitable areas for Norse settlement in northeastern North America, and they indicate that climatic variability also affected Norse settlement in Iceland. While there are minor variations in the expression of the Norse niche within each major climatic episode (*i.e.*, the Medieval Warm Period and the Little Ice Age), the overall trend shows a contraction of the geographical expression of the ecological conditions occupied by Viking populations. Future work needs to focus on quantifying this reduction and determining whether this contraction represents an actual contraction of the eco-cultural niche, or whether it simply reflects the fact that Viking populations conserved their niche and tracked its shrinking footprint during the climatic deterioration of the LIA.

Such work may also serve to identify the reason behind the slight geographic expansion of the Norse niche during the 15th century, which is an intriguing result considering that it occurs during the period that saw the eventual abandonment of Viking settlements in Greenland. Two hypotheses to explain this pattern could be tested. The first hypothesis postulates that rigorous environmental conditions during the 13th and 14th centuries were sufficient to adversely affect and disrupt local and interregional Viking economies, and when combined with other impacts from disease, piracy, and conflicts with indigenous populations (Dansgaard *et al*., 1975; Keller, 1991; Dugmore *et al.*, 2012), the result was that Viking populations had been adversely impacted by these conditions such that they were unable to respond to a slight period of climatic amelioration. Ultimately, Norse populations were unable to adapt to the LIA and Greenland settlements were abandoned (see Barlow *et al.*, 1997). A second hypothesis is that Viking populations were able to adapt by modifying their agrarian adaptations and adopting subsistence

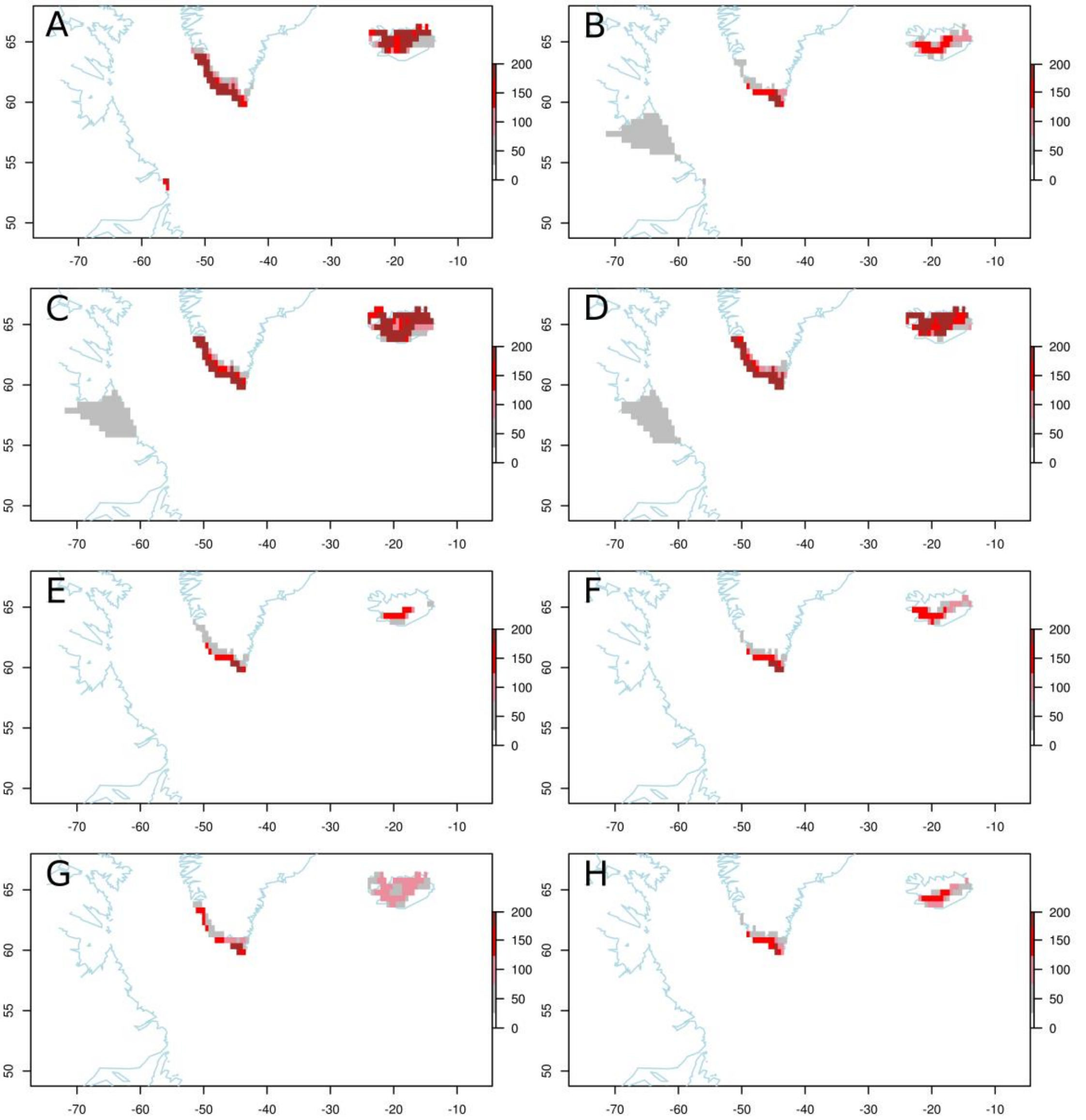

Figure 5: Century-scale variability of the Viking eco-cultural niche. The 11th century Norse eco-cultural niche and its projection onto the climatic conditions of other centuries. (A) projection onto the 9th century, (B) projection onto the 10th century, (C) projection onto the 11th century, (D) projection onto the 12th century, (E) projection onto the 13th century, (F) projection onto the 14th century, (G) projection onto the 15th century, (H) projection in climatic environment for the 16th century. These niche reconstructions represent the sum of the 200 produced models and grid square color ranges from grey, to pink, to red, and to brown, or low to high probability: grey = 26–75 models in agreement, pink = 76–125 models in agreement, red = 126-175 models in agreement, and brown = 176-200 models in agreement. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

methods practiced by indigenous populations, as suggested by Annerborg (2012). Although unlikely, this hypothesis proposes that a Norse presence, albeit reduced, continued in Greenland but became archaeological invisible with respect to its "Viking" signature. One possible way to test this idea is to reconstruct eco-cultural niches based on Iniut archaeological site datasets and compare these results to Norse eco-cultural niche predictions.

Finally, at present, our archaeological and paleoclimatic data have limitations that need to be addressed before future studies may proceed. The attribution of archaeological sites to either the first or second settlement datasets needs to be refined through more detailed analyses of material culture as well as relative and absolute dating techniques. Such work ultimately will allow for more accurate eco-cultural niche predictions. With respect to the climatic data, the data used in this study were simple interpolations of Jungclauss' global climate models. Thus, we would need to apply statistical downscaling techniques to increase the resolution of climatic variables for the targeted time periods. At present, we are collaborating with paleoclimate modelers in order to apply state of the art statistical downscaling techniques (Levasseur *et al.*, 2011) to global simulations that cover the last millennium. With such an approach we can expand the number of climate variables considered, such as relative humidity and wind. Another option, albeit more difficult, is to produce high-resolution paleoclimatic simulations for the MWP and LIA. Once such work has been completed, with these higher-resolution climatic data layers, we will be able to produce more robust eco-cultural niche predictions that better reflect past reality and thereby test the preliminary results obtained with the present study. Moreover, with more precise and robust niche predictions, we will be able to apply statistical methods to identify and evaluate possible niche shifts over time (*e.g.*, partial-ROC methods: Peterson *et al*., 2008; see Banks *et al*., 2012 for an archaeological example).

5. Conclusions

The demise of the Norse occupation of Greenland represents one of the few known historical cases in which climate change may have functioned as the prime mover in such cultural (settlement and subsistence) dynamics. Our preliminary results suggest that this is likely the case, but further work incorporating more precise archaeological and paleoclimatic data is necessary to refine and possibly confirm our findings. This additional work will also allow us to better identify and evaluate the environmental factors that played a principal role in the settlement variability documented in the Viking archaeological record. Finally, it may also be possible, albeit difficult, to evaluate the hypothesis that Norse populations adopted more arctic-adapted subsistence practices to the degree that they become archaeologically unrecognizable as Vikings.

Name	Meaning	Unit
EPTo	mean of equivalent precipitation temperature for October	$kg.m^{-2}.s^{-1}$
EPTa	mean of equivalent precipitation temperature for April	$kg.m^{-2}.s^{-1}$
EPTj	mean of equivalent precipitation temperature for July	$kg.m^{-2}.s^{-1}$
EPTy	mean of equivalent precipitation temperature for the year	$kg.m^{-2}.s^{-1}$
MSLPo	mean sea level pressure at the surface for October	Pa
MSLPa	mean sea level pressure at the surface for April	Pa
MSLPj	mean sea level pressure at the surface for July	Pa
MSLPy	mean sea level pressure at the surface for the year	Pa
T2Mo	contains air temperature at 2m for October	K
T2Ma	contains air temperature at 2m for April	K
T2Mj	contains air temperature at 2m for July	K
T2My	contains air temperature at 2m for the year	K
SSRo	surface solar radiation for October	K
SSRa	surface solar radiation for April	K
SSRj	surface solar radiation for July	K
SSRy	surface solar radiation for the year	K
DEM	elevation	m

Table 1: Climatic variables derived from the paleoclimatic simulation and their abbreviations.

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