



## Medieval Iceland, Greenland, and the New Human Condition: A case study in integrated environmental humanities

Steven Hartman<sup>a,b,\*</sup>, A.E.J. Ogilvie<sup>b,c</sup>, Jón Haukur Ingimundarson<sup>b,d</sup>, A.J. Dugmore<sup>e,f</sup>,  
George Hambrecht<sup>g</sup>, T.H. McGovern<sup>h,b</sup>

<sup>a</sup> Mid Sweden University, Department of Tourism Studies and Geography, 831 25 Östersund, Sweden

<sup>b</sup> Stefansson Arctic Institute, Borgir, Nordurslóð, IS-600 Akureyri, Iceland<sup>d</sup>

<sup>c</sup> Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309-0450, USA

<sup>d</sup> University of Akureyri, Faculty of Social Sciences, Borgir, Nordurslóð, IS-600 Akureyri, Iceland

<sup>e</sup> Institute of Geography, School of GeoSciences, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, Scotland, UK

<sup>f</sup> School of Human Evolution and Social Change, College of Liberal Arts and Sciences, Arizona State University, Tempe, AZ 85287-2402, USA

<sup>g</sup> University of Maryland College Park, Anthropology Department, College Park, MD 20742, USA

<sup>h</sup> Zooarchaeology Laboratory, Anthropology Department, Hunter College CUNY, 695 Park Ave NYC, 10065, USA

### ARTICLE INFO

#### Keywords:

Environmental humanities  
Global change  
Historical climatology  
Historical ecology  
Icelandic sagas  
Medieval Iceland  
Political ecology  
Zooarchaeology

### ABSTRACT

This paper contributes to recent studies exploring the longue durée of human impacts on island landscapes, the impacts of climate and other environmental changes on human communities, and the interaction of human societies and their environments at different spatial and temporal scales. In particular, the paper addresses Iceland during the medieval period (with a secondary, comparative focus on Norse Greenland) and discusses episodes where environmental and climatic changes have appeared to cross key thresholds for agricultural productivity. The paper draws upon international, interdisciplinary research in the North Atlantic region led by the North Atlantic Biocultural Organization (NABO) and the Nordic Network for Interdisciplinary Environmental Studies (NIES) in the Circumpolar Networks program of the Integrated History and Future of People on Earth (IHOPE). By interlinking analyses of historically grounded literature with archaeological studies and environmental science, valuable new perspectives can emerge on how these past societies may have understood and coped with such impacts. As climate and other environmental changes do not operate in isolation, vulnerabilities created by socioeconomic factors also beg consideration. The paper illustrates the benefits of an integrated environmental-studies approach that draws on data, methodologies and analytical tools of environmental humanities, social sciences, and geosciences to better understand long-term human ecodynamics and changing human-landscape-environment interactions through time. One key goal is to apply previously unused data and concerted expertise to illuminate human responses to past changes; a secondary aim is to consider how lessons derived from these cases may be applicable to environmental threats and socioecological risks in the future, especially as understood in light of the New Human Condition, the concept transposed from Hannah Arendt's influential framing of the human condition that is foregrounded in the present special issue. This conception admits human agency's role in altering the conditions for life on earth, in large measure negatively, while acknowledging the potential of this self-same agency, if effectively harnessed and properly directed, to sustain essential planetary conditions through a salutary transformation of human perception, understanding and remedial action. The paper concludes that more long-term historical analyses of cultures and environments need to be undertaken at various scales. Past cases do not offer perfect analogues for the future, but they can contribute to a better understanding of how resilience and vulnerability occur, as well as how they may be compromised or mitigated.

\* Corresponding author.

E-mail addresses: [steven.hartman@miun.se](mailto:steven.hartman@miun.se) (S. Hartman), [astrid.ogilvie@colorado.edu](mailto:astrid.ogilvie@colorado.edu) (A.E.J. Ogilvie), [jhi@unak.is](mailto:jhi@unak.is) (J.H. Ingimundarson), [ajd@staffmail.ed.ac.uk](mailto:ajd@staffmail.ed.ac.uk) (A.J. Dugmore), [ghambrecht@gmail.com](mailto:ghambrecht@gmail.com) (G. Hambrecht), [h.mcgovern@gmail.com](mailto:h.mcgovern@gmail.com) (T.H. McGovern).

<sup>1</sup> The Icelandic language contains the letters *ð* (upper case *D*) pronounced like the “th” in “clothe” and *þ* (upper case *P*) pronounced like the “th” in “thing”. Unless in a quotation or a personal name, the letter “þ” is transliterated to “Th” throughout the paper.

## 1. Introduction

The New Human Condition addressed in this special issue recasts Hannah Arendt's landmark concept in the light of the Anthropocene (Crutzen and Stoermer, 2000). What gave Arendt's conception of *the human condition* (Arendt, 1998) such convincing force in the mid-twentieth century was a recognition that modernity had made possible ever-greater scales of human loss, such as global-scale conflicts in the form of the two world wars, the genocides of the Gulag and the Holocaust, and the prospects of global annihilation ushered in with the Atomic Age. In the face of the enormous scales of these tragedies we could "no longer go back to traditional concepts and values, so as to explain the unprecedented by means of precedents, or to understand the monstrous by means of the familiar" (d'Entreves, 2014). Early in the twenty-first century we see an analogous situation with the transformative escalation of earth-system changes, many of them human-driven (Waters et al., 2016). The concept of the New Human Condition in the present special issue, as transposed from Hannah Arendt's influential work, admits the role of human agency in altering the conditions for life on earth, in large measure negatively, while acknowledging the potential of this self-same agency, if effectively harnessed and properly directed, to sustain essential planetary conditions through a salutary transformation of human perception, understanding and remedial action.

This paper draws upon long-term international, interdisciplinary research in the North Atlantic region, and collaborative projects focusing upon human impacts on island landscapes, climate-change impacts on humans and nature, and the interactions of human societies at different scales. It illustrates the benefits of a more fully integrative approach making use of the tools of Historical Ecology (Crumley, 2007), as part of both the Integrated History and Future of People on Earth (IHOPE) and the Circumpolar Observatory of the Humanities for the Environment (HfE) global observatory network. The paper argues for increased integration of environmental humanities and social science perspectives in global environmental-change research programs.

The great environmental predicament of our age is not primarily an ecological crisis, though its ramifications are far reaching within ecological systems; rather it is a crisis of culture (Hartman, 2015). Bound into this predicament is a global overdependence on fossil-fuel energy within an economic system (free-market capitalism) that rarely bears the true costs of human labor, resource consumption, and biodiversity loss, to name but a few of the *wicked* problems of the twenty-first century. Unsustainable agricultural activities and resource flows, or geopolitical instabilities leading to civil strife and forced migration, can be counted among numerous other complex triggers of, and responses to, environmental change. The processes by which societies negotiate environmental challenges and respond to threats are neither natural nor a matter of scientific understanding in the classic sense. They are cultural transactions explicable via modes of inquiry traditionally encompassed within the social sciences and humanities.

An integrated approach that draws upon the data, methodologies and analytical tools of multiple disciplines within the humanities, social sciences and natural sciences is demonstrated in this paper, through an examination of two closely related island communities, Iceland and Greenland, with a primary focus on Iceland and a secondary comparative focus on Greenland. The specific time period considered is the late-twelfth through the early-fourteenth centuries. We consider climate change as a driver of socioecological stress and investigate how variations in climate have the capacity to directly affect societies. We do not subscribe to the narrow doctrine of environmental determinism because climate change does not operate in isolation; prior vulnerabilities created by human drivers determine the scale of impacts. Thus the socioecological settings of climate are key to understanding drivers of change, and impacts need to be understood in that context. Our focus

is on a marginal set of environments where climate changes in the past have crossed key natural thresholds for agricultural productivity. By focusing on past societies with more limited connectivity than today we can also consider changes that affected entire communities, mimicking the all-encompassing scales of contemporary change. Future scales of change are likely to cross comparable thresholds within key zones of human activity (for example, sites of cereal production approaching the limits of arable farming). Such perspectives on past changes may thus be used to anticipate and illuminate processes driving future change.

## 2. Past to future global changes

As we move further into the twenty-first century, global change is likely to pose unprecedented threats to human societies in terms of the regions and numbers of people affected by climate change. New extremes will be encountered and the unusual is most likely to become common. The 1:100 year flood, storm, drought, heat wave or freeze could become a regular occurrence and even more infrequent extremes previously encountered once in a thousand years or more may become ever more commonplace (AHDRI, 2004, 2015; Arctic Report Card, 2016).

The scales of future global change may be unprecedented in terms of their magnitude and spatial extent. Comparable magnitudes of change have occurred in the past on local scales. In a more sparsely populated and less interconnected world a prolonged drought or sudden cooling could rock a small community's entire world. Death could come on a scale that the vast majority of present generations have never experienced. The plagues of medieval Europe and the mass dying that followed post-Columbian European contact with the Americas shattered entire societies. Threats both from nature and human interactions with the environment have been experienced throughout history. A long-term perspective enables us to explore how the impacts of realized threats may have played out over the years and decades following notable, system-affecting events. By more thoroughly exploring the relationships between the nature (and scale) of threats and their consequences for human societies, we may achieve a better understanding of how human communities can become vulnerable or resistant, or how people at various scales within these societies may cope with threats or be overwhelmed by them.

Research collaboration unfolding under the aegis of IHOPE and HfE is aiming to fill gaps in knowledge related to the human dimensions of global change processes. This paper draws upon interlinking work from two such projects, *Inscribing Environmental Memory in the Icelandic Sagas* (IEM) and *Comparative Island Ecodynamics* (CIE),<sup>2</sup> which foreground elements and approaches generally underrepresented in global change research.

The first of these underrepresented elements is a concerted integration of expertise from the natural and social sciences through the humanities, including a much wider spectrum of disciplines than the global change community has engaged previously in any systematic way. The question of what can lead us to a sustainable future is ultimately too complex to be understood, much less resolved, within the boundaries of single disciplines. A framing of the human dimensions of environmental change requires drawing upon multiple specialized fields of knowledge pertaining to human activities and their consequences at wide-ranging scales of impact. The research groups collaborating within the IHOPE Circumpolar Networks program have developed an integrated framework for transdisciplinary collaboration "defined by a radical openness to disciplinary border crossing that

<sup>2</sup> IEM is an unfolding experiment in Integrated Environmental Humanities (IEH) led by the Nordic Network for Interdisciplinary Environmental Studies (NIES, <http://bit.ly/2oZLXyO>) and the North Atlantic Biocultural Organization (NABO, <http://www.nabohome.org>). Together with CIE, IEM anchors the Circumpolar Networks program of IHOPE (<http://ihopenet.org>), a core project of Future Earth (<http://www.futureearth.org>).

aligns physical environmental studies with aesthetic, ethical, historical and cultural modes of inquiry" (Hartman, 2016). The trans-domain cooperation of integrated environmental humanities, social sciences and natural sciences actualized in this program seems to be without precedent in the global change research community, insofar as it integrates researchers from fields of study as diverse as literature, history, archaeology, anthropology, geography, geosciences, palaeoecology, life sciences, digital humanities, cyber infrastructure, environmental arts, and education for sustainability. These collaborations, carried out in distinct but overlapping sub-project teams, allow not just for multidisciplinary crowd-sourcing of data and expertise concerning questions of common interest, but also for a crucial coalescence of diverse fields of inquiry that address human agency — causes, influences and effects — in relation to environmental change. The relevance and respective balance of disciplinary inputs from social science, humanities and natural science disciplines vary in these sub-projects according to what research questions are addressed. For this reason, co-design and co-execution of research, as well as co-dissemination of results, whenever possible, are important principles guiding how new research projects may be organized within the program. This paper represents an effort to co-disseminate integrated research findings in a more fully transdisciplinary way. It does so by moving beyond the theoretical, methodological or communicative limitations of scientific publication typical of more loosely framed multidisciplinary articles. Such dissemination outputs tend to reflect the disciplinary interests, norms and expectations of a dominant discourse or research community at the expense of others contributing significantly to the study and its overall (integrated) findings. The paper thus aims to demonstrate not only the interconnectedness of different research questions but also the collective benefits of opening up distinct knowledge silos and specialist toolboxes for a more synergistic production of new knowledge.

Another clear priority in the research emerging from the IHOPe Circumpolar Networks is the recovery of valuable knowledge from material cultural evidence of the *human* past; an element that has been underrepresented in global change research. Reconsideration of socio-ecological change on time scales far greater than those of living or recent memory need to build on bodies of evidence that long precede modern instrumental records. To help plan for future implications of human-environment interactions we need to better understand those of the past. Valuable research has been undertaken in recent years on strategies of adaptation to socioecological risks and threats (see, e.g., Adger et al., 2009), but the great majority of these are firmly rooted in the present or the very recent past. Longer-term historical analyses of cultures and environments on the scale of multiple generations, centuries, or even on a millennial scale, need to be undertaken. Far more research is needed that spans periods of known change. Such knowledge can help us to understand the significance of path dependency and how rigidity traps can develop, why past decisions matter, and how adaptations that have utility in one set of circumstances can become a liability in another. The past offers no perfect analogues for the future, but it can help us to better understand how both resilience and vulnerability are developed, how Traditional/Local Ecological Knowledge is created and transmitted as an intangible resource, how strategies can be devised to help anticipate future threats and cope with difficult times, how environmental threats and risks are remembered over the course of many generations, and also how they are sometimes forgotten. Our consideration of the possible impacts of hierarchy, conformity, networks, investment in fixed infrastructure, and attachment to place on the resiliency of future societies can only be enriched by a fuller understanding of past human responses to environmental change. By considering the long term we can assess how both 'elegant' and 'clumsy' solutions meet the challenge of climate change and assess the effects of conjunctures (see e.g., Dugmore et al., 2012).

### 3. Regional setting: Climate and environment of Iceland and Greenland

Although the climatic regimes of Iceland and Greenland are different, the climate systems that affect them are closely linked by virtue of proximity and the atmospheric circulation system of the North Atlantic. Greenland has a polar climate, seasonal sea ice, and a short growing season that is marginal for trees even in sheltered inland valleys of the southwest. In comparison with Greenland, Iceland enjoys a relatively mild climate thanks to the warming effect of the Irminger Current. Although roughly 10% of the island is covered by glaciers, in favored parts trees may flourish and cereal cultivation is now possible, though environmentally marginal. As Iceland is located close to both the atmospheric and oceanic Polar fronts, comparatively minor fluctuations in the movement of air masses and ocean currents have a great impact on Iceland's climate, and may drive threshold-crossing variability on all time scales, from days and weeks to decades and centuries. The seasonal limit of the Arctic drift ice lies close to Iceland and is an extremely important feature of its climate (Ogilvie, 1984; Ogilvie, 1986; Ogilvie, 2010; Ogilvie and Jónsson, 2001a). The presence of sea ice off the Icelandic coast can negatively affect vegetation growth by lowering local air temperatures. In past centuries the impacts on people have included reductions in grazing and fodder production, the prevention of sea fishing and the disruption of trade. The effects of sea ice are nuanced and not always unfavorable for human society; the ice can also bring opportunities, such as ice-riding seals, thereby providing a vital alternative food source for people (Ogilvie, 1984, 2005, 2010). Overall, however, it has been argued persuasively that sea ice has had a more detrimental effect on environment and society in Iceland than other natural hazards such as volcanic eruptions and earthquakes (Thoroddsen, 1914).

Geologically, Iceland and Greenland are very different. Greenland is dominated by its vast inland ice sheet, and the bedrock exposed around the margins is characterized by very old crystalline rocks of the Precambrian shield, which are up to ca. 4000 million years old (Henriksen et al., 2009). The bedrock in the areas of Greenland settled by the Norse includes outcrops of Precambrian shield and sandstones, lavas and igneous intrusions older than 1600 million years. Iceland, in contrast, is geologically a very young country created by volcanic activity over the last 18 million years (Einarsson, 1994). Volcanic eruptions of varying magnitude are frequent. There is written evidence, as well as geological records, that around 205 volcanic eruptions have occurred in Iceland since the Norse settlement, although we know this record is not complete, and the true total is likely to be closer to 300 events (Thordarson and Larsen, 2007). Virtually every type of volcanic activity found on Earth occurs in Iceland (Thordarson and Larsen, 2007) and some events have had devastating effects on the human population, not least when they occurred in conjunction with vulnerabilities created by people, severe weather or sea ice (Ogilvie, 1986; Dugmore and Vesteinsson, 2012).

Iceland has often been called the "Land of Fire and Ice" from the physical hazards it has faced in the form of ice, both glacial and sea ice, and fire, as volcanic activity (Thórarinsson, 1956). The hazards posed by volcanism, in particular, are one example of how long-term perspectives can help to illuminate the challenges of the New Human Condition. Volcanic eruptions can range on a scale from minor to catastrophic. Some can occur on such scales that they are outside the previous experience of living human beings or beyond the scope of available, even longer-term environmental memory. The local effects can be devastating, with wholesale changes in environments. They can include lava flows, lahars, ash falls, poisonous gases, landslides, floods, and tsunamis (Guðmundsson et al., 2008). Large eruptions can also have global effects, including abrupt changes in air quality and temperature (Harington, 1992; Demarée and Ogilvie, 2001). Fig. 1 shows Öræfajökull, an outlet glacier of Vatnajökull in southeast Iceland. The volcanic eruption of Öræfajökull in 1362 devastated the nearby farming



**Fig. 1.** The photograph shows a Great Skua (*Stercorarius skua*) flying over Hornafjörður in southeast Iceland. The area is one of the main breeding grounds for these birds. In the background is Öræfajökull, an outlet glacier of Vatnajökull. Considerable melting has taken place in recent decades and the nearby glacial lagoon Jökulsárlón featuring calving icebergs has become a major tourist attraction (see Fig. 3). The area features in *Njál's Saga* as the character Flosi Þórðarson, one of the leaders of the group who burn the eponymous character and his family alive in their home, lived there at a farm called Svínafell. The region was devastated in 1362 after a volcanic eruption in Öræfajökull. Photograph: Þorvarður Árnason.

community and the name was subsequently changed from *Litla Hérað* (the “Little District”) to *Öræfi*, the “Desert” (Thórarinsson, 1958).

#### 4. Historical-ecological context

Iceland and Greenland were settled by people deriving primarily (if indirectly in Greenland's case) from the linguistically and culturally cohesive region known in modern times as Scandinavia, with significant migration from the British Isles as well (also indirectly in Greenland's case, though among the first wave of settlement in Iceland). Both societies were established in the Viking Age: Iceland ca. 871<sup>3</sup> and Greenland ca. 985. In Iceland migrants of the late-ninth century Norse *Landnám*, or large-scale settlement, would have encountered extensive birch woodlands that are likely to have covered at least a quarter of the island and been found across the lowlands and within sheltered valleys. Birch-willow scrub would have extended into more exposed areas of upland, coast and marginal wetlands and willow tundra would have existed in the highlands (Blöndal and Gunnarsson, 1999). Before settlement, this landscape was not grazed by terrestrial mammals, as these were represented solely by the Arctic fox (*Vulpes lagopus*). Human colonization brought about wholesale ecological change through the introduction of numerous domesticated fauna of sheep, goats, cattle, horses and pigs, which became the key drivers of subsequent vegetation changes and extensive soil erosion, ultimately resulting in a reduction of woodland to less than 2% of the total land area (Dugmore et al., 2005, 2014). In Greenland, Viking-Age settlers would have encountered a similar, but even more depauperate subset of the Boreo-temperate northwestern European flora, grazed in this case by caribou. Despite extensive inland ice and a harsher climate, limited areas of birch and willow scrub would have been found in sheltered inland valleys along with some substantial tracts of rangeland for seasonal grazing (Madsen, 2014).

The communities of Norse Greenland and Iceland shared a cultural and biological heritage, and for nearly five centuries they represented the westernmost outposts of Christendom. However, the different paths

chosen, and their long-term fates present stark contrasts. In spite of environmental, economic, and even epidemiological challenges, Iceland survived to become a fully developed twenty-first century Nordic society, whereas Norse Greenland had ceased to exist by the end of the fifteenth century. Both cases have been used in discourses around the idea of “collapse” (Diamond, 2005) and they remain active subjects for international interdisciplinary research transecting different scientific domains (Ogilvie, 1998, 2010; Dugmore et al., 2012, 2013; Frei et al., 2015; Hartman et al., 2016). These radically different outcomes of environmental and societal stresses provide an opportunity to examine the responses of two culturally and biologically similar societies to multiple challenges and opportunities. The focus in this paper is on the period from the end of the twelfth century through the beginning of the fourteenth century, a time when significant changes occurred both in social and environmental spheres.

Professional archaeological investigations were first undertaken in both Iceland and Greenland in the early-twentieth century. Since the 1970s there has been a veritable explosion of new archaeological work in both regions. This research has yielded extensive and highly resolved datasets that are helping to reshape the prevailing understanding of human ecodynamics in the North Atlantic during the past 1000 years.<sup>4</sup> Parallel with this development have been great advances in the field of climatology and the emergence of a wide variety of sub-disciplines, including environmental and climate history. Of particular relevance here is the great expansion in the availability of “proxy” climate data. These are drawn from natural archives such as ice and sediment cores, tree-rings, glacial records, and corals, to name a few (Jones and Mann, 2004). Such sources provide information on changes in climate prior to the era of systematic meteorological observations. One further type of proxy data comes from documentary written records. The analysis of information from these records is known as historical climatology. As with archaeological data, this research area has engendered a large

<sup>3</sup> All dates given are AD/CE. Current research on the dating of the settlement of Iceland gives possible constraining dates of  $871 \pm 2$  and  $877 \pm 4$  but the date may be slightly earlier; for discussion see Batt et al., 2015.

<sup>4</sup> The results of much of this research are available on the website of the North Atlantic Biocultural Organization (NABO): <http://www.nabohome.org>. Through coordinated projects related to the International Polar Year (2007–11), and later under the aegis of the Comparative Island Ecodynamics (CIE) Project (2012–15), studies from the NABO research community have focused increasingly on the diverging pathways and outcomes of these Norse medieval colonies in the North Atlantic.

body of new knowledge in recent decades. The field may be said to have begun in the nineteenth century with the production of compilations of weather and climate information. The compilers were generally unaware of the need for source criticism. Thus a crucial development in this field was the recognition by climate historians of the need to place this discipline on a sound methodological footing, and to emphasize the importance of rigorous historical source analysis (Vilmundarson, 1972; Bell and Ogilvie, 1978; Ingram et al., 1978, 1981; Wigley et al., 1981). The value of historical climatology for climate reconstruction is emphasized in numerous studies and the wealth of information available attests to the fact that historical data can provide precise and accurate descriptions of past weather and climate when interpreted knowledgeably and with care. Of the hundreds of papers published on this topic, a handful of examples are given here (Le Roy Ladurie, 1972; Ogilvie, 1982, 1992, 2010; Bradley and Jones, 1992; Pfister and Brázdil, 1992; Brázdil, 1995; Martin-Vide and Barriendos, 1995; Pfister et al., 1998, 1999, 2017; Jones et al., 2001; Ogilvie and Jónsson, 2001b; Brázdil et al., 2005; Wheeler and Suarez-Dominguez, 2006; Garcia-Herrera et al., 2008; Jones, 2008; Maelshagen, 2014; Luterbacher et al., 2016; White et al., 2017). Although documentary climate data for Europe become more prolific subsequent to the medieval period, research specifically into the climate of this earlier period has produced much information of value (see e.g., Alexandre, 1976, 1987; Ogilvie, 1991, 1998, 2010; Ogilvie and Farmer, 1997; Stern, 2000; van Engelen et al., 2001; Ludlow, 2010; Pribyl et al., 2012; Camenisch et al., 2016) as well as much discussion (see e.g., Hughes and Diaz, 1994; Bradley et al., 2003, 2016; Jones, 2008; Diaz et al., 2011; Young et al., 2015; Campbell, 2016).

A number of valuable studies of climate variations for Iceland have been carried out based on different proxy data sets. However, a discussion of these is beyond the scope of this paper which focuses specifically on the exceptionally rich written sources for medieval Iceland (sagas, law codes, annals, landholding documents and a variety of other texts). These would typically have been written on vellum and were often beautifully illustrated. An example is given in Fig. 2 of a manuscript from the fourteenth century containing law codes. These documents open up opportunities to evaluate an indigenous record of local human responses to environmental and economic changes that is unique in the circumpolar north, not only for its historical depth but also for its local production and regional focus. This paper makes use of some of these resources, concentrating on analysis of environmental information in Icelandic documents that is especially promising for cross-disciplinary collaboration bridging the environmental humanities, archaeology and global change science.

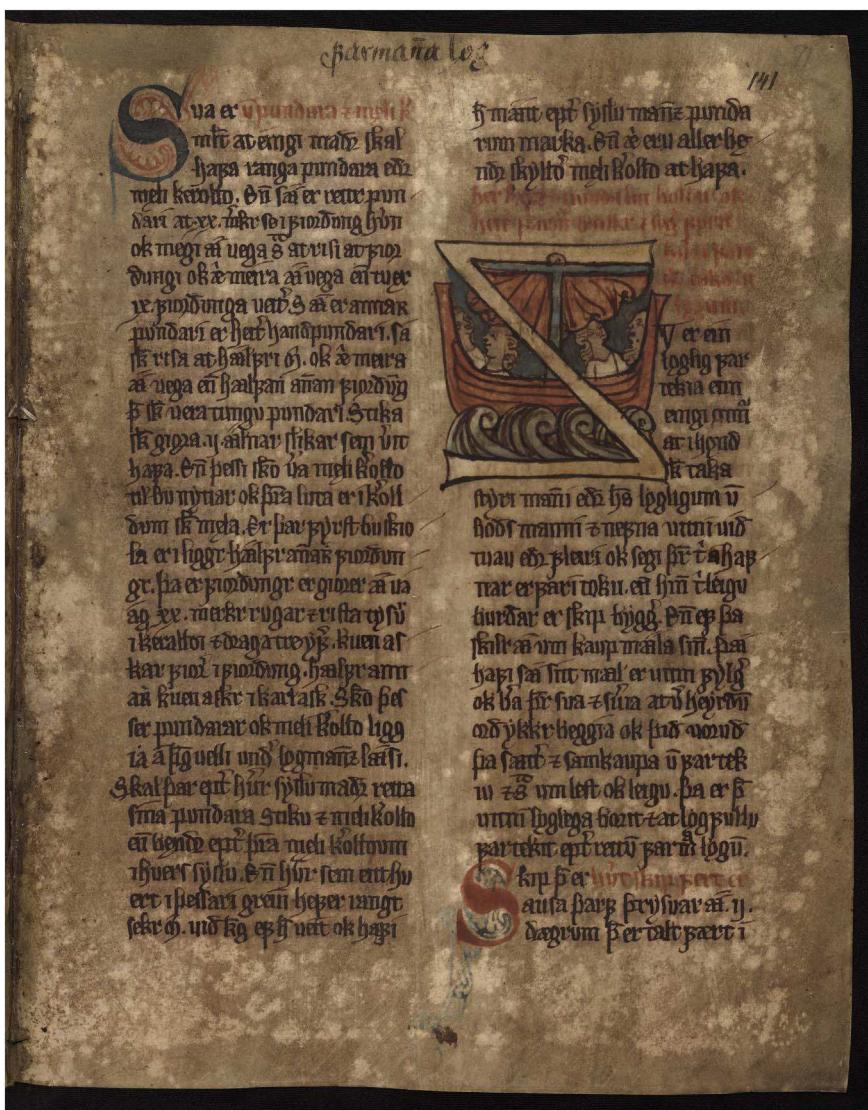
The exact nature of the climate of medieval Iceland and Greenland is a topic that has given rise to debates among historians, climatologists and others from the early twentieth century to the present day (see, e.g., the discussion in Ogilvie and Jónsson, 2001a). With regard to the climate of this period much has been made of the concept of a "Medieval Warm Period". This was coined by the climatologist Hubert Lamb (1965) and was defined by him as a time of "warm climate" during 1000 to 1200. However, he based the concept on anecdotal evidence, which does not stand up to examination (Jones, 2008). One example concerns the cultivation of vines in medieval England. There was nothing unusual in this. Viticulture was practiced in Britain throughout the past millennium. There were certainly no more vineyards in medieval times than during the present day – 52 are recorded in the *Doomesday Book* of 1086, whereas approximately 350 can currently be found in England and Wales (Jones, 2008). In other words, medieval vine growing in England has no bearing on the climate of the time. The term "Medieval Climate Anomaly" is a term chosen by Stine (1994) to refer to regional hydrological anomalies in the twelfth and fourteenth centuries. As noted by Bradley et al. (2016) "in many studies that use these terms the period of time to which they refer is commonly not defined; indeed, they may only be vaguely alluded to when an anomaly in a time series roughly falls within the interval from A.D. 500–1500".

As further research is undertaken, it becomes increasingly clear that the concept of a "Medieval Warm Period" is overly simplistic (Jones, 2008; Ogilvie, 2010; Young et al., 2015). What is evident from the historical data is that North Atlantic climate in the medieval period was highly variable; in particular, two *cold* periods stand out in Iceland, the first around the end of the twelfth century, and the second at the end of the thirteenth century (Bergþórsson, 1967; Ogilvie, 1991). These episodes are also found in the records of glacial advances (Guðmundsson, 1997; Kirkbride and Dugmore, 2008) and in a number of palaeoclimatic records (see e.g., Miller et al., 2012) and appear to have been implicated in famines and attendant difficulties of the time.

In Iceland, volcanism was no less important than climate. When people settled Iceland in the late-ninth and early-tenth centuries they probably encountered volcanism for the first time, as there were no active volcanoes in their Scandinavian and Celtic homelands. Mediterranean volcanism may have been encountered by a few of the first settlers, but no previous Scandinavian community had directly experienced volcanic ash falls, air pollution, lava flows or volcanically induced floods. All of these were encountered by the third decade of the tenth century with the massive *Eldgjá* eruption in southern Iceland — the largest known volcanic eruption of historical times with an output of about 20 km<sup>3</sup> Dense Rock Equivalent of lavas and ash (Thordarson and Self, 1993; Thordarson and Larsen, 2007). Other major eruptions followed in 1104, 1300, and 1362, and these were interspersed with many other volcanic events on smaller scales (Thórarinsson, 1958, 1967). What is quite remarkable is how few Icelandic volcanic eruptions of any sort have resulted in major death tolls (Ogilvie, 1986; Karlsson, 2000), with some notable exceptions, such as the *Lakagígar* eruption of 1783–84 when a quarter of Iceland's population died (Demarée and Ogilvie, 2001).

The high medieval period is also notable for several key developments in economic and political spheres: conflicts among economic elites in Iceland; growing tensions between powerful secular landholders and the church; and contraction of settlements in Greenland. These were related to changes in subsistence economies in both Iceland and Greenland as well to the new challenges and opportunities afforded by the economic and political expansion of the Norwegian realm (which incorporated both islands in 1262–64). The period of ca. 1200–1350 thus appears to have been an era of challenge and response for these communities on the edge of medieval Europe, a conjuncture of climate, culture, and economy that was to set these two societies on increasingly divergent pathways (Nelson et al., 2015; Dugmore et al., 2012, 2013). It is of particular interest that at the same time that these difficulties were occurring, historiography and saga writing in Iceland were reaching their zenith (Sigurðsson, 2004; McTurk, 2004; Hartman et al., 2016).

The development of rich vernacular Icelandic literary and historiographic traditions arose from the unusual circumstances by which Christianity and ecclesiastical establishments originated, developed and operated in the eleventh and twelfth centuries on this rural island located far from urbanized Europe, its archbishoprics and the papacy. Christianity was accepted as the official religion at a meeting of the national assembly (Althing) in the year 999 or 1000. Throughout Iceland prominent farmers had churches built on their private land following acceptance of a law that concerned collection of tithes (ca. 1097 — see also Section 8) and thus became church-owners who formed congregations or parishes. Priests served as their employees, subordinates, or direct dependents, and were supported in their education by the patron farmer. The emerging Church in Iceland eventually saw the establishment of the Skálholt bishopric in the south in 1056, and the Hólar bishopric in the north in 1106. Several monasteries were established during the twelfth century, possibly even earlier. However, the Church in Iceland was long based on very close ties to rural communities of farmers. This circumstance required the development of a written language in the Icelandic vernacular that would lay the foundation for widespread literacy, as well as for rich bodies of secular narrative and normative literature. A strong oral tradition had existed



**Fig. 2.** This example of an Icelandic illuminated manuscript is from a fourteenth-century legal codex (GKS 3269 4to, 71r). The codex is generally referred to as *Jónsbók* after its compiler, Jón Einarsson (d. 1306). The page shown refers to laws regarding merchants. The manuscript is held by the Árni Magnússon Institute for Icelandic Studies and permission has kindly been granted to reproduce it here. Photograph: Jóhanna Ólafsdóttir.

in Iceland before a vernacular writing culture developed under the influence of the Church's import of alphabetic literacy, and literary works dealing with the Icelandic past undoubtedly drew upon this tradition. Oral transmission of genealogical information in the vernacular tongue had played a key role in preliterate Icelandic society, not least in preserving and transmitting information relevant to legal questions of ownership and property inheritance. Laws were orally transmitted in pre-literate Iceland. Every year at the Althing it was the lawspeaker's duty to recite from memory one third of the full body of Icelandic law. This practice became obsolete after the law was written down for the first time in 1117–18, though traditions of oral poetry, storytelling and historiography almost certainly played some meaningful role in the development of the large corpus of native vernacular literature for which medieval Iceland is now famous (for further discussion of early literary culture in Iceland see Hartman et al., 2016).

## 5. Settlement and economy in Viking Age and early medieval Iceland and Greenland: The archaeological record

Multiple excavated animal bone collections (archaeofauna) indicate that Iceland and Greenland each initially utilized the standard set of Eurasian domestic animals (horse, cow, sheep, goat, dog, and pig),

supplemented by extensive use of wild animals (fish, birds, sea mammals and, in Greenland, caribou). The sporadic cultivation of barley and flax in Iceland (and possibly in a few areas of Greenland) is indicated by carbonized grain and some pollen records (Einarsson, 1994; Trigg et al., 2009) as well as documentary evidence (Ogilvie, 1991, 2005). In both islands settlement was dispersed with scattered farmsteads ranging in size from large manors housing dozens of kin and servants to tiny cottages and seasonally occupied shielings (see, e.g., Madsen, 2014). Despite this dispersed pattern, pooling of communal labor and resources was a regular feature of subsistence, and the unit of survival was far larger than the individual farm. In both communities, fodder production in summer was critical to the survival of domestic stock (especially cattle) during the winter. The specter of late winter shortfalls in stored fodder and human provisions was a recurring threat to North Atlantic farmers (McGovern et al., 1988; Ogilvie, 2001) even in the earliest periods of settlement, and farmers worked hard to maintain their infield pastures with fertilization and small-scale irrigation systems. Soil erosion has also been a significant problem since early times (Amorosi et al., 1997; Simpson et al., 2001; Adderley and Simpson, 2006). On the Greenlandic home farms, shorter growing seasons constrained stock production. Livestock probably spent nearly 9 months a year inside being hand-fed fodder harvested in autumn (McGovern,

1985a, 1985b; Enghoff, 2003). Nevertheless, cattle, the highest value domesticate, were still maintained on all farms. Ratios of cattle to sheep and goat (caprine) bones vary in both Greenlandic and Icelandic archaeofauna of the Viking Age and early medieval period (with the greatest relative proportion of cattle bones on the largest farms with the best pastures), but generally fall below five caprine to one cow — suggesting only sporadic surplus wool production and a focus on household provisioning (McGovern et al., 2014; Smiarowski et al., 2017). Fragments of woolen cloth and many finds of weaving equipment (Hayeur-Smith, 2011, 2013) indicate widespread household-level cloth production, but with wide variability in type and quality. In Iceland, goats become increasingly rare after the Viking Age, but in Greenland goat bones remain common (often outnumbering sheep bones) through to the end of the settlement. Pig bones become increasingly rare in both Icelandic and Greenlandic archaeofauna after ca. 1100 (McGovern et al., 2007, 2009; Harrison, 2013).

In Iceland, the old Nordic pattern of harvesting marine fish, especially from the cod family (*gadidae*), which could be air dried and stored without salt for years, is evidenced by finds of processed headless marine fish in multiple archaeofauna on inland sites 60 km or more from the sea: material dated by volcanic ash (tephra<sup>5</sup>) and radiocarbon to ca. 875–933 (McGovern et al., 2006; Batt et al., 2015). This pattern seems to reflect an early internal trade in artisanal dried fish, with higher diversity in species and fish-cutting techniques evident than in later periods (Amundsen et al., 2005; McGovern et al., 2006; Perdikaris and McGovern, 2008a, 2008b).

Norse Greenlandic settlers encountered four species of arctic seals (harp, hooded, ringed and bearded) that are infrequent visitors to Iceland. Immense populations of migratory harp and hooded seals riding drift ice and arriving in southwest Greenland in the spring had immediate and lasting impacts on Norse subsistence (Ogilvie et al., 2009). Current archaeological evidence dating to the early settlement period (McGovern, 1985a; McGovern et al., 2014; Smiarowski et al., 2017) indicates a rapid shift in the use of marine species by the colonists. The marine fishing and dried fish production (standard in Iceland) seems to have been immediately supplanted by large-scale (probably communal) hunting of migratory harp seals. However, the Norse Greenlanders did not take significant numbers of the non-migratory arctic ringed and bearded seals associated with winter breathing holes and fast ice, whose bones are very rare in Norse collections but common in Greenlandic (non-Norse) archaeofauna of all periods. The Norse apparently did not make extensive use of the harpoon-based winter sea-ice sealing practices of either the Dorset or Thule arctic hunting peoples (Storå and Lõugas, 2005), relying on communal sealing methods characteristic of Norse sea-mammal hunting in the eastern North Atlantic. The hunting of seals was far less important in Iceland, but was not insignificant. The main seal species encountered off Iceland's coasts are harbor or common seals and the grey seal. Fig. 3 shows common seals resting on an ice floe in the glacial lagoon Jökulsárlón in southeast Iceland.

Both island communities were engaged in transatlantic trade with Europe, and both initially focused upon the harvesting of walrus ivory for export (Pierce, 2009; McGovern, 1985b; Frei et al., 2015; Hambrecht, 2015). In Iceland walrus remains disappear from the archaeological record within a century of settlement, suggesting that the Icelandic walrus populations were not robust enough to withstand sustained human predation, and Icelandic exports shifted to dried fish and woolen cloth. In Greenland the walrus hunt remained important to the end of the settlement's existence. Annual walrus hunting trips were launched to the Norðursetur (Disko Bay, where large walrus rookeries

are located), lying up to 800 km north of the settlements. The archaeological evidence for this long-range hunt has been found in virtually every Norse Greenland farm site in the form of fragments of walrus maxilla from around the tusk root, a by-product of ivory processing. These fragments indicate widespread community participation in ivory preparation (McGovern et al., 1996). The long-range Norðursetur walrus hunt appears to have been of a very different character from the exploitation of nearby local walrus rookeries documented from early Iceland, and it appears to have remained one of the centrally important activities in the colony until the end of its existence. Rather than a more traditional colonial narrative centered on a desire to expand farming territory, recent research on the Greenland Norse colony has emphasized long-distance trade in Arctic luxuries (ivory and furs) as the primary motive behind the settlement, and Greenlanders may have paradoxically been more closely tied to distant European markets than their cousins in Iceland (McGovern, 1985b; Dugmore et al., 2007; Frei et al., 2015).

By the early twelfth century, Iceland's population had probably neared its pre-modern maximum of 50,000–60,000, supporting two bishoprics and many large estates. Greenland remained much smaller with a community probably no larger than 2000–3000 that eventually supported a bishop's manor, multiple stone churches, a monastery and a nunnery (Madsen, 2014; Arneborg et al., 2009). Both colonies saw a similar social and political development; each witnessed an accumulation of power and property at the top of the social structure at the expense of the middle and lower estates (Vésteinsson, 2007, 2010; Arneborg, 2012; Arneborg et al., 2012). By 1200, Iceland and Greenland were small but successful societies, with developed European medieval social hierarchies. They shared the same Eurasian domestic animal husbandry economies and each was engaged in transatlantic trade and exchange. However, these societies took very different paths when it came to their exploitation of wild resources for subsistence and trade. Fig. 4 shows the ruin of the magnificent stone church at Hvalsey in the region of the Norse Eastern Settlement in southern Greenland.

## 6. High medieval changes

In the mid-thirteenth to early-fourteenth centuries a conjuncture of local, regional, social, economic, and environmental changes placed significant stresses on these two Norse communities, while also introducing new opportunities. Although Iceland and Greenland were at the westernmost extreme of Eurasian/African trade networks, the *Pax Mongolica* and its generation of a medieval world system (Abu-Lughod, 1981) had significant impacts on these colonies. Iceland was clearly connected to the larger world on multiple levels. Archaeologically, this can be seen in the presence of seasonal trade centers along the Icelandic coast. Excavations of these trading sites have confirmed documentary references to medieval trade in Icelandic falcons and sulfur, yet the major exports seem to have been woolen cloth and dried fish (Harrison, 2013, 2014a, 2014b).

Coastal fishing sites also appear to increase in numbers and distribution in Iceland after ca. 1250 (Amundsen et al., 2005). These sites show a clear "producer signature", meaning that they were producing cured fish products for local, regional and increasingly long-distance trade. The transformation of cured fish products into fungible commodities can be seen clearly in the changing nature of the bones recovered from such sites: e.g., through more selective harvesting of species, with a more exclusive focus on Atlantic cod, and preparation that favored a standardized stock fish (Perdikaris and McGovern, 2008b).

In the thirteenth century some Icelandic farms show a dramatic change in the percentage of domestic animals, with sheep eventually becoming dominant over cattle, a pattern that continued into the twentieth century. Goats and pigs become very rare, and the data suggest a higher proportion of older (and larger) sheep that were likely maintained for wool production (McGovern et al., 2007; Harrison,

<sup>5</sup> Tephrochronology is a dating technique based on the identification, correlation and dating of layers of volcanic ash (tephra). Tephra layers form isochrons that can be traced over very wide areas and offer dating control that is both precise and accurate, especially when the ages of the tephra layers are derived from reliable written sources (Thórarinsson, 1944, p. 1–217).



**Fig. 3.** The practice and history of seal hunting in Iceland has been documented in great detail by Luðvík Kristjánsson (1980) and is clearly as old as the first settlement. Seals appear to have been an important addition to the daily diet, especially at times when other traditional food sources failed. Several proverbs testify to this fact, including *Selurinn er sela í búi*: ("A seal means contentment in the home"). In Norse Greenland this pattern of small scale hunting changed dramatically with seals becoming increasingly important for subsistence. The photograph shows common seals (*Phoca vitulina*) on a calving iceberg in the glacial lagoon Jökulsarlón in southeast Iceland. Öræfajökull can be seen in the background. Photograph: Þorvarður Árnason.



**Fig. 4.** One of the very last written records giving information concerning the Greenland Norse is to be found in an entry in the Icelandic Annals for 1408. This entry documents the wedding of Sigríður Björnsdóttir and Þorsteinn Ólafsson, both from Iceland. The photograph shows the ruin of Hvalsey church, originally built ca. 1250, where the marriage was solemnized on 16 September 1408. The church is adjacent to the Hvalsey fjord near modern-day Qaqortoq in the Norse "Eastern Settlement" area. *Hvalsey* means "Whale Island". Photograph: Astrid Ogilvie.

2013). Paralleling this development, woolen cloth fragments show standardization into a legally defined commodity (Hayeur-Smith, 2013).

By the late-thirteenth century Icelandic marine fishermen and wool producers were generating products according to standards dictated by distant but powerful markets (Vésteinsson, 2016). Standardization can be seen clearly in the archaeological record. Export based on low-value, but high-volume, commodities eventually became an important part of medieval Iceland's economy and connection to the wider world.

In Greenland, however, there is no indication of similar alterations

in the relation of subsistence and surplus production for trade (McGovern et al., 1996, 2014; Smiarowski, 2012, 2014). Documentary records indicate that while hundreds of kilos of Greenlandic walrus ivory were still being collected in the mid-fourteenth century, this product was increasingly difficult to market profitably in Europe (Frei et al., 2015). So despite economic change in Europe, ivory production and the system that underpinned it endured in Greenland. There is also other evidence of economic conservatism as the percentages of cattle to caprine remain fairly stable on larger manor farms, but on small to medium sized holdings cattle become far less common than sheep and

goat bones after ca. 1300 (Smiarowski et al., 2017).

No evidence for standardization of woolen cloth production has yet been identified in the Greenlandic collections (Hayeur-Smith, 2013). The Greenlanders kept to their initial market of high-value, low-volume Arctic luxuries: ivory and furs. The growth of high-volume, low-margin commodities has been argued to be an important part of the growth of medieval European economies (Hoffmann, 2014). Iceland seems to have participated in this phenomenon while Greenland kept to their older original model, suggesting a reversal in the relative connectedness of these island societies to mainland Europe that is evident by the late-thirteenth century. In other words, Norse Greenlanders appear to have stuck to a Viking Age model of trade and economic markets, thereby weakening their economic connection to mainland European markets, whereas Icelanders seem to have adapted to a shift in economic systems during the high medieval period.

In this context it is noteworthy that there were several cold years with sea ice in Iceland in the latter part of the thirteenth and early part of the fourteenth century. It is likely that pasture productivity declined in both Iceland and Greenland during these times. Increased sea ice would have impacted transoceanic voyages, local travel, and non-migratory seal colonies in Greenland (Ogilvie et al., 2009). Although a colder climate in Iceland did not necessarily mean similar conditions in Greenland, archaeological research indicates that the Norse Greenlanders also experienced climate shocks in the later thirteenth century, and that they survived these shocks by intensifying their communal seal-hunting strategies, which took place in the exposed outer fjords, to compensate for stress on the farming economy (Madsen, 2014; Arneborg et al., 2012; Dugmore et al., 2012). There is evidence that around 1425 a second climate shock impacted the whole region, with a dramatic increase in storminess (Dugmore et al., 2007). The successful Greenlandic response to the initial climate impact in which they increased their reliance on the hunting of migratory seals in the outer fjords may have rendered this small community tragically vulnerable to loss of life at sea in a radically stormier North Atlantic. By the end of the fifteenth century Norse Greenland had ceased to exist.

It is possible that the Icelanders were subjected to the same increase in storminess, although there is no direct evidence of this. However, another factor did indeed cause great loss of life: the ravages of plague, probably the Black Death, which occurred in 1402 (Streeter et al., 2012). Iceland's larger population and more robust export economy (which produced calories as well as wealth) may have provided the resilience needed to overcome climatic and biological stresses.

While the society of Norse Greenland had ceased to exist by the end of the fifteenth century, Icelandic society survived, with an economy that now appears comparatively complex and diverse (Boullosa, 2012). Currently, Iceland consistently ranks among the highest achieving nations globally in indices of human development and well-being (Human Development Report, 2015; OECD, 2015).

In sections 7–8 of this paper we turn to documentary records to continue exploring the evidence for medieval climate change and for societal response strategies. In respect to these sources a stark contrast exists between Iceland and Greenland. Virtually no documentary records were produced in Greenland, and what is known regarding Norse Greenlandic society from written records comes primarily from Iceland (Halldórsson, 1978; Ogilvie, 1998). On the other hand, documentary records are unusually rich for Iceland during this historical period, as can be seen below.

## 7. Historical climate data from Iceland

The past climate and sea-ice record from Iceland is based primarily on detailed documentary evidence (Ogilvie, 1984, 2005, 2008, 2010). A pioneer in this field was the Icelandic geographer and geologist Þorvaldur Thoroddsen (1855–1921) who spent a lifetime gathering climate information from the Icelandic records which was published in a compilation (1916/17). However, as with other compilations,

erroneous information crept in (Vilmundarson, 1972; Bell and Ogilvie, 1978; Ogilvie, 1984, 2010). The sources discussed here have all been analyzed individually (Ogilvie, 1991, 2010). Documentary sources concerning the climate of Iceland from the late-twelfth to the early-fourteenth centuries include certain saga genres: for example, works from the *Sturlunga Saga* collection, which include a number of separate sagas.<sup>6</sup> Information used in this paper is drawn from three of these: *Íslendinga saga*, *Pórðar saga kakala*, and *Svínfellinga saga*. The *Sturlunga Saga* collection covers the period known as the “Age of the Sturlungs” (ca. 1220 to 1264), named for one of the leading families of the time. This was a period of great internal strife in Iceland that ended only with the country's acceptance of the overlordship of the Norwegian king. The Bishops' sagas, narratives of the lives of Icelandic bishops, are also important sources. The medieval Icelandic annals comprise a further major historical source (Ogilvie, 1991, 2005; Hartman, 2016).

In addition to these kinds of sources, medieval ecclesiastical charters (for example, census deeds and inventories) are also preserved in the collection of medieval Icelandic historical documents known as *Diplomatarium Islandicum*. These have been analyzed (Ingimundarson, 1995, 2010) in regard to changes in ownership of livestock and property, rent agreements and stipulations of law, in order to decipher changes in subsistence base, forms of tribute and exports, the vegetation decline of the era, and the diverse outcomes of cooperation and conflict between landowners and peasants in different regions, especially during the decades of unfavorable weather at the end of the twelfth and thirteenth centuries. All these documentary records comprise the main sources for the medieval period regarding political, social, and also climatic events. Documented climate and weather events in Iceland are discussed in this paper in relation to climate impacts that appear to have accompanied severe years in the 1180s and 1190s and around 1300.<sup>7</sup>

Analyses of historical data show highly variable temperatures and sea-ice incidence over the past  $\geq 1000$  years (Ogilvie, 1984, et seq.). From around 1600 there is sufficient documentary evidence to construct indices of sea-ice and temperature data (Ogilvie, 2010; Miles et al., 2014). These show marked variability through to the present day. The last great subsistence famine in Iceland occurred in the 1880s when sea ice was present during several years and temperatures were very low (Ogilvie, 2005, 2010). While some sea-ice years occurred in the 1890s, they were fewer than in the 1880s. From 1900 onwards sea-ice incidence falls off dramatically until the so-called “Ice Years” of 1965–1971 (Dickson et al., 1988). In recent years, the lack of ice in Icelandic waters is in line with diminishing Arctic sea ice (Serreze and Stroeve, 2015).

Prior to 1600, the historical record is sporadic; however, there are several references to the occurrence of sea ice off the coasts. The first

<sup>6</sup> Where an English translation of an Icelandic source is quoted we use the English convention regarding titles. Hence “*Sturlunga Saga*”. Where the original Icelandic source is referred to we use the Icelandic convention. Hence “*Íslendinga saga*” and so on. Where we refer to a genre or category of sagas that nevertheless do not appear as a published compilation we do not include italics (e.g. “Bishop's sagas”) so that these manuscript sources are not confused with published sources.

<sup>7</sup> Information drawn from documentary sources concerning the climate of Iceland in the medieval period is discussed extensively in Ogilvie, 1991, 2005, 2010. Detailed discussion of these documentary sources, covering their provenance and value, and the importance of carefully analysing historical climate information to ensure reliability, may be found both in these papers and in others (Ogilvie, 1992; Ingimundarson, 1995). The medieval deeds and charters drawn upon in this paper have largely been used previously by researchers working in the field of ecclesiastical history. Ingimundarson's ongoing research uses the economic information in these sources to complement the work of Ogilvie on Iceland's climate history, and to cast light on economic changes impacted by climatic and environmental factors, as well as social and political events. Further studies from Ogilvie and Ingimundarson based on analysis of medieval Icelandic documentary sources are forthcoming in the context of IEM and CIE collaborations with the co-authors of this paper, as well as other collaborating researchers in the Circumpolar Networks program of IHOP. For a useful concise overview of the varieties and genres of medieval Icelandic sagas, with an emphasis on the history of literature and environment, see also Hartman et al., 2016.

unquestionable reference to sea ice off the Icelandic coasts in the documentary records is for the year 1145 when the Icelandic annals (IV, VIII) state laconically: “Much ice” (Storm, 1977, p. 114, 321).<sup>8</sup> Historical sources begin to become contemporaneous at this point in time, due to the rise of alphabetic literacy and literate culture under the influence of Christian institutions in the twelfth century (Hartman et al., 2016). Consequently, there is little reason to suspect that sea ice had not appeared prior to this account. Additional sporadic weather descriptions hint at much variability in the period up to end of the twelfth century. Multiple sources (e.g. the *Sturlunga Saga* and the Bishop’s sagas) suggest the occurrence of severe seasons in the 1180s and 1190s. These sources also document a spell of severe weather in the first few years of the thirteenth century. Around this time the medieval Icelandic annals also provide some interesting information. For example, *Höyer-sannáll* (III) notes the following details for the year 1203: “Ice lay fast to the land at the time of the Annunciation of Mary (25 March/1 April) so that it was impossible to get access to the sea from Saurbær [in Snæfellsnes district]. Before *Seljumannamessa* (8/15 July) 30 men crossed on the ice from the island of Flatey [in Breiðafjord] to the mainland” (Storm, 1977, p. 62). In 1204 severe hardship is recorded in one of the Bishop’s sagas, *Guðmundar saga biskups Arasonar* (the “*Saga of Guðmundur Arason*”) by Árngrímur Brandsson: “The first winter that the Bishop Guðmundur took up his seat at Hólar there was great distress and dearth afflicting the people so that many poor people died of hunger” (*Guðmundar saga biskups Arasonar*, p. 56). This source is not contemporary but is to some extent corroborated by *Páls saga biskups* (the “*Saga of Bishop Páll*”), which refers to a scarcity of food affecting both livestock and human beings that *may* apply to 1204 (pp. 27–28). Over the next few years there are several references to both “good” and “severe” seasons (Ogilvie, 1991). In 1233 a severe winter occurred. In *Íslendinga Saga* it states: “That was a harsh, severe winter, and throughout the countryside people found conditions very hard on their livestock” (*Sturlunga Saga*, p. 361). *Skálholtsannáll* (V) notes “the great ice winter” and the annals specifically mention sea ice “all summer” for this year (Storm, 1977, pp. 129, 187). The descriptions of sea ice in 1203 and 1233 are the first to give details of when it occurred.

A description in *Íslendinga saga* suggests that a volcanic eruption with an ash-fall had occurred during the winter of 1226–27: “This year was known as the sand-winter and it was a very hard winter for the livestock. One hundred head belonging to Snorri Sturluson died at Svignaskarð” (*Sturlunga Saga*, p. 315). In 1236 *Íslendinga saga* mentions that “In the winter there had been good weather” but the spring was severe. “Fourteen horses died at Æðey [in the Ísafjord district in the northwest] on Ascension Day (8/15 May) whilst men were eating and there was every prospect of devastation in Ísafjord before the fish would be coming in at Kvíarmið” (*Sturlunga Saga*, p. 391). The same saga refers to the spring of 1238 as very good and specifically mentions Apavatn, near Skálholt (*Sturlunga Saga*, p. 412). *Pórðar saga kakala* refers to a spell of cold and frosty weather in the autumn of 1242 (*Sturlunga Saga*, p. 18). A severe winter is recorded in 1251–52 in *Svínfellunga saga* (*Sturlunga Saga*, p. 97). However, *Íslendinga saga* notes that in 1254 “the winter was so good that men knew of none like it” (*Sturlunga Saga*, p. 496). A severe spring in Skagafjord in the north is reported for 1258 in *Borgils saga skarða* (*Sturlunga Saga*, p. 222). For the year 1261 the annals (I, III, IV, V) say there was “sea ice around Iceland” (Storm, p. 300). This year is also recorded as being severe in *Íslendinga Saga*: “That was a harsh winter and men had to kill much of their livestock” (*Sturlunga Saga*, p. 527). This is the last weather reference contained in the *Sturlunga Saga* collection but, from the late-thirteenth century onwards, information in the annals becomes fuller and more detailed.

Some further light on the climate of the period ca. 1240–1260 is

shed by a non-Icelandic work known as the *Konungs Skuggsjá* (“The King’s Mirror”), which was probably composed in Norway ca. 1250 (Holtsmark, 1956–78). This interesting work has much to say on the climate of Iceland and Greenland. Iceland’s glaciers are mentioned as a notable feature of the country. In the medieval author’s opinion, the presence of ice on the island’s higher grounds is due to Iceland’s close proximity to Greenland, which is covered with ice more than any other country, and “since ice takes so much cold from there and receives little warmth from the sun there is great abundance of ice on its mountains” (Larsen, 1917, p. 126). Sea ice is referred to as one of the marvels of the sea between Iceland and Greenland: “As soon as one has crossed over the deepest part of the sea he will encounter such masses of ice that I know of nothing like it anywhere else on the earth” (Larsen, 1917, p. 138). Though the text does not explicitly state that sea ice ever comes to the coasts of Iceland it would probably be mistaken to conclude that sea ice was rare near land. Despite the many excellent features of this source, it is unlikely that the author had ever been to Iceland, though he doubtless had informants who had been there (Ogilvie, 1991).

There is no more weather information in the Icelandic sources until the 1270s when *Gottskálsannáll* (VIII) refers to “twenty-two polar bears killed in Iceland” in 1274. This same source states that in 1275: “twenty-seven polar bears [were] caught in Iceland. Sea ice around nearly the whole of Iceland” (Storm, 1977, p. 332). Polar bears are not indigenous to Iceland but are occasionally brought by the sea ice, a fact that was clearly well known to the author of the annal, and to medieval Icelanders in general (Ogilvie, 2005). Mention of polar bears’ occasional presence in Iceland has even been used as proxy evidence to suggest that sea ice was present (Teitsson, 1975). It seems likely these two accounts refer to just one event, probably in 1275. In some late, and manifestly unreliable, sources this event is transposed to 1279 (Ogilvie, 1984).

The sources are silent again until the 1280s. For the years 1284 and 1285 *Árna saga biskups* (the “*Saga of Bishop Árni*”) states: “That winter ... a great dearth occurred in the north ... This calamity spread to the south in the next winter” (*Árna saga biskups*, 1972, p. 117). This saga is an excellent general source — unfortunately it says nothing specific about weather conditions. Other sources refer to difficulties at this time but without offering precise details. *Laurentius saga* (the “*Saga of Bishop Laurentius*”) describes an epidemic in 1284 and adds that there were “livestock deaths and many people died of hunger in Iceland and many farms were deserted ...” (*Laurentius saga*, 1969, p. 11). Some of the annals also mention sickness in 1284, or 1285: for example, “much sickness in the western fjords” (II) and “in the south” (VIII) (Storm, p. 337). An interesting description occurs in *Lögmansannáll* (VII) for the year 1287: “At this time many severe winters came at once and following them people died of hunger” (Storm, 1977, p. 260). This suggests that the difficulties in 1284 and 1285 mentioned in *Árna saga biskups* most probably were associated with severe winters.

In 1291 the annals refer specifically to a severe winter: “[a] great snow winter” (II, III); “the great livestock death winter” (I, IV); “[a] great ice and livestock-death winter” (IV); “severe winter” (VII) (Storm, 1977, pp. 30, 51, 71, 143, 197, 338). It seems likely that the whole of Iceland was affected. In 1292 an epidemic and mortality is mentioned (III, V) (Storm, 1977, p. 71, 197). There is “great lack of grass” in 1293 (VIII) (Storm, 1977, p. 338). One manuscript of this source adds “drought summer”. That there were severe years toward the end of this period is also suggested by an interesting decree of King Eirík Magnússon of Norway for 1294: “We do not wish that much dried cod should be exported to Norway while there is a dearth in the country” (*Diplomatarium Islandicum* II, 1857-, p. 287).

There is more information on climate and weather during the fourteenth century than any other during the medieval period. Most of this comes from the annals, which are now almost all contemporaneous. The new century began with an eruption of Hekla (II, III, IV, V, VII, VIII) and the severe dearth mentioned in the north in the summer of 1300 was likely precipitated by this event (Storm, 1977, pp. 52, 72, 146, 199,

<sup>8</sup> The 11 medieval Icelandic annals now extant are published in Storm, 1977. All translations from the Icelandic in this section are by A.E.J. Ogilvie. For a discussion regarding the different annals see Ogilvie (1991).

262–63, 339). Other natural disasters during the first decade of the fourteenth century included epidemics, mortality, and earthquakes. However, only one event that refers specifically to the climate is mentioned. This is the sea ice during the summer of 1306. "Sea ice all summer in the north" (IV, V, VIII) (Storm, 1977, pp. 53, 148, 201, 340).

In summary, for the period under discussion there are reliable historical data that are contemporary. These climate data are often related to human experiences of dearth, hunger and death. As vulnerabilities to climate impacts are created by the decisions people take, and the social structures, economic systems, patterns of security and insecurity that result, this perspective on the human experience is most valuable and makes an important connection that is often difficult to make from a simple proxy of a climatic variable such as air or sea-surface temperatures.

Although glacier fluctuations may be partially decoupled from climate they do reflect an interplay between temperature, precipitation and ice dynamics. In general, conditions that see a build-up of glacial ice (through lower summer temperatures and more snowfall) make pastoralism harder (Casely and Dugmore, 2007). The broad pattern of the data from written sources is consistent with geomorphological data on advances of the glacier Gígjökull (an outlet glacier of Eyjafjallajökull) occurring between the tenth and twelfth centuries (Kirkbride and Dugmore, 2008). While the glaciological data lack the resolution to make precise correlations, the latter period certainly fits well with the historical data for the years ca. 1180 to 1210 as a relatively cold period is suggested then. Cold periods occurred again during the 1280s and 1290s. Severe sea-ice years are noted around 1233, 1261, and 1306, although it is very likely that these represent only the "tip of the iceberg" of actual sea-ice years. The cold period around 1300 is well documented in written sources (Berghórsson, 1969; Ogilvie, 1991). Palaeoglacial work (see, e.g., Guðmundsson, 1997) also indicates major glacial advances at that time.

Further evidence from the archaeological record is also relevant: for example, an archaeofauna recovered from a midden (garbage deposit) at the site of Hofstaðir near Mývatn in northeastern Iceland that appears to have formed in the last decades of the thirteenth century but which was redeposited on the surface of a volcanic ash layer dated to ca. 1300 (the H 1300 tephra). This archaeofauna has some unusual features that distinguish it from the much larger archaeofauna from the same site dating to the Viking Age (McGovern et al., 2013). The more recent bone collection contains sheep and cattle bones that were highly fragmented, with some processed to extract the last collagen ("bone grease"). It also contained the partly-articulated remains of at least four dogs (two adults and two puppies) and one adult cat. Dog and cat bones are very rare in any Icelandic midden context, and these can conceivably connect to a reference dealing with famine strategies from the *Sagas of Icelanders* (see Hreinsson, 1997): "No less, we shall abolish the wicked custom which has prevailed here, of keeping large numbers of dogs with food that could sustain many people. The dogs must be killed, and few or none left alive, and the food which was before given to them shall now be used for human nourishment." This is from the "Tale of Svadi and Arnor Crone's Nose" (*Svaða þáttur og Arnórs kerlingarnefs*).<sup>9</sup> The same archaeofauna collection contains a large number of bones of harp seals, normally associated with drift ice, and a partially articulated common porpoise spine. This deposit suggests both a "hard times" scenario and a cultural response by these inland farmers now making increased use of marine resources. Changing emphasis from terrestrial to marine resources may well have been a widespread response, and with further research the documentary record may allow us to go from anecdotal case study to a fuller regional perspective.

## 8. Shifting the balance in northwest Iceland: Documentary evidence for climate impacts

Studies of economic processes and fluctuations within Iceland, with a particular focus on the Strandir area of northwest Iceland, have highlighted some of the impacts of unfavorable weather during extended periods near the end of the twelfth century and again at the end of the thirteenth and beginning of the fourteenth centuries (Ingimundarson and Ogilvie, 1998a, 1998b). Here it may be noted that there is a statistically demonstrable and close correlation between adverse weather and grass growth (in particular cold and/or variable spring growing seasons, very wet or very dry summers, and wet harvest seasons). Lack of grass for hay feed over the winter could result in loss of livestock due to starvation. This was a common occurrence in Iceland's history, and frequently resulted in unfortunate social effects, including malnutrition and famine for the human population (see e.g., Ogilvie, 2001).

In Iceland the value of milch cows, leased or sold, appears to have decreased during the relatively cold last decades of the twelfth century and around 1200 (Jóhannesson, 1956) relative to the price of homespun (*vaðmál*).<sup>10</sup> This may suggest that land had become relatively more expensive as a result of a less favorable climate, with severe weather adversely affecting vegetation growth and thereby possibly increasing population pressure. However, as Helgi Þorláksson (1991) has suggested, the harsh weather conditions causing the loss of many cattle at the beginning of this extended cold period, i.e. during the winters of 1186 and 1187, would help explain why the standard "cow's value" (*kúgildi*) stated in the Helgafell ecclesiastical charter dated 1186 is as high as 120 ells. Furthermore, a transformation away from an intensive mercantile economy (yielding surplus wool for export) and toward a farming system that included fewer dairy cows and dry cattle and an increasing number of sheep reared for efficient milk and meat production may have accelerated during this harsh period (Ingimundarson, 1995). Sheep became an expanding source of direct subsistence, as flocks increased the number of yearling and older female sheep. Farmers came to rely more on keeping ewes in order to have milk for themselves; hence lambs had to be sustained through at least a second summer growth spurt before becoming effectively reproductive or yielding significant meat and fleeces.

The available zooarchaeological evidence in the thirteenth and fourteenth centuries suggests a shift away from intensive cattle keeping on some farms (where ratios of cattle to caprine bones go as high as 1:25), with sheep flocks managed for wool and meat production becoming widespread (McGovern et al., 2014). While more collections from more regions within Iceland are needed, this trend is consistent with both a general increase in wool production and a risk-spreading strategy that favored less expensive animals over the increasingly valuable and vulnerable cattle.

An increase of the sheep population may have caused the advent of vegetation decline and soil erosion due to overgrazing in certain regions around 1200 (Arnalds, 1992). Rangeland soil erosion in Iceland is dominated by aeolian processes and results in a reduction in soil area. As a result, aeolian sediment accumulation rates (SeAR) in soil profiles can be used as a proxy for both local and regional soil erosion (Dugmore and Erskine, 1994; Dugmore et al., 2009). In general, lowland areas settled by people (below c. 450 m elevation) undergo SeAR increases after *Landnám* (the Icelandic settlement period of ca. 870–930) that rise to levels well outside those of the previous 2500 years (Streeter et al., 2015). Before *Landnám* lowland sites are typified by high proportions of *Betula* (birch) in the pollen record and low SeAR, but after settlement there is a general shift to lower proportions of *Betula* and higher SeAR,

<sup>9</sup>This is from the manuscript collection known as *Flateyjarbók*, and the tale (trans. Scilla Brumfit) is found in the collection the *Complete Sagas of Icelanders* vol. V, p. 356, ed. Hreinsson, 1997.

<sup>10</sup>*Vaðmál* was the homespun cloth that served as an important monetary standard in early Iceland. It was measured in ells (*dnir*), representing the length and width of the cloth. In medieval Iceland an "ell" was approximately 457 mm (18 inches).

with rises in SeAR preceding the reduction of *Betula* by about 100 years (Streeter et al., 2015; Vésteinsson et al., 2014). Sharp increases of soil erosion during the tenth century and subsequent accelerations during the sixteenth and nineteenth centuries stand out above an overall rising trend, but in the first few centuries of settlement there are great local variations from little change to significant regime shifts that reflect the crossing of local threshold conditions (Streeter and Dugmore, 2014). Locally there is evidence of enhanced erosion before 1300 (Dugmore et al., 2006).

The periods of severe weather at the end of the thirteenth century, and around 1300, would have had prolonged and repeated adverse effects on vegetation growth, resulting in frequent and significant losses of livestock and most certainly leading to an increased dependency on fishing and exploitation of other marine resources, as illustrated below by the case of Strandir.

The standard milch cow — which had been valued at as low as 72 and 90 ells of *vaðmál* in the decades around 1200 (Ingimundarson, 1995; Thoroddsen, 1919) and variously at 90, 96, and 120 ells until around 1280 (Jóhannesson, 1928; Þorláksson, 1991) — had reached the consistent value of 120 ells by around 1300, most likely due to frequent and widespread death of livestock (Ingimundarson and Ogilvie, 1998a, 1998b; Þorláksson, 1991). Furthermore, interest on leasing of livestock went up to as high as 16.66% (Þorsteinsson and Grímsdóttir, 1989), from 10%, which was the “lawful interest rate” on land and livestock according to both the medieval Icelandic books of law known as *Grágás* and *Jónsbók* (see Fig. 2 for an illustration of a page from *Jónsbók*). Leasing of livestock had become widespread at this point, and ecclesiastical (church, episcopal and monasterial) estates, in particular, increased their titles to land, causing an increase in the number of tenants as the number of freeholders declined (Jóhannesson, 1974).

In attempting to compare and contrast various impacts of the two extended cold periods at around 1200 and 1300, respectively, it is important to take into consideration the pronounced thirteenth-century processes of increased consolidation of land, and a concurrent expansion of tenure systems whereby ecclesiastical and secular landowners rented out land and dairy-cattle and provided tenants with access to communal grazing land. An increasing number of smallholders had lost both control of, and direct access to, cattle and their products on the domestic market, as well as strong incentives and capabilities for cultivating hayfields, producing quality hay for cattle and ewes, rearing wethers, and providing milk for their lambs (Ingimundarson, 2010). The product forms and currencies acceptable as land-rent, cattle-leasing and tithe payments were neither unchanging nor invariable; the economic ruling classes were only able to siphon from peasants' surpluses in accordance with the economic survival strategies of those peasants and with their own strategies of accumulation, both of which were changing. For example, while homespun, tufted wool cloaks and fleeced lambskins had been highlighted among acceptable forms of tithe payment in the twelfth century, butter, cheese, hay and the winterfeeding of livestock had become dominant forms of tithe payment in the thirteenth century, whereas after 1300, fish, blubber and whale are increasingly mentioned in the documentary records as additional forms of payment (Ingimundarson, 1995).

One example may be offered here to illustrate the major changes taking place in land-tenure systems by considering two inventories for the Tröllatunga church situated adjacent to Steingrímsfjord in the Strandir region for 1274 and 1317 respectively (*Diplomatarium Islandicum* II, 1893, p. 119, 407–409). First, the charter for 1317 states that Tröllatunga must receive half a *centner* (a *centner* equalled 45.36 kg — hence 22.69 kg in this case) of dried fish from each of the parish farms (i.e., over and above regular tithe payments, which decrease during hard times when the farm animal stocks are smaller). The imposition of a fish tax on all parish farms, whether they were on the coast or not, suggests that at some point after 1274 a widespread increase in fishing activity began to develop among all, or most, parish households,

or at least increasingly tight ties of exchange and interdependence between coastal and non-coastal households. Three issues are of particular relevance. First, the Tröllatunga ecclesiastical estate did not include a coastal area, did not own a beach area, and did not have direct access to the sea. Second, the number of livestock earmarked as church property falls from thirty ewes, seven cows and one horse in the 1274 inventory, to three ewes and five cows in the 1317 inventory. (It is important to keep in mind that a church owner and warden (*kirkjueigandi*) would be committing a major offence if he declared a reduction of church property, unless death or destruction could be blamed, or if he could show that one type of property had been converted into another, for example from livestock to land.) Third, while Tröllatunga owned: i) the entire home estate; ii) two dependent farms (*hjáleigur*, outlying farms); iii) and also “indirect access” to small woodlands and to beaches for driftwood and stranded whales in 1274, by 1317 the Tröllatunga church had also acquired the entire adjacent Arnkötłudalur valley and titles on the farmsteads and holdings of Arnkötłudalur and Hólsland, suggesting that these two farms may have been adversely affected by the hard times.

Considering the impact of severe climatic conditions and severe weather events, it can be suggested that ordinary freeholders and tenants were losing animals year after year, causing some of the freeholders to sell part or all of their land to the church (or to the church-warden himself) in order to acquire replacement animals (some leased, others bought in the exchange) and thus considerably reduce their tithe payments. Both factors, fewer animals in smallholders' private possession, and the selling of land titles to the church, worked toward reducing revenue from tithes — a gradual tax-system introduced in 1097, especially the two portions (of four) which were to go to the Bishop and the priests: hence the struggle between the church-wardens and the Bishop. The properties of the church were tax-exempt and the church-owner was in control of the tithe quarter collected toward church maintenance. However, the Bishop also watched over the interest of priests who were their economic eyes and ears. Smallholders must not have been able to pay much to anyone in severe years, but the church-owners and ecclesiastical estates were able to make long-term investments. Also, in the short term, they would cut their losses through collecting some land rents (as well as wood, peat, beached whales etc.) as well as interest on the animals that were leased out. It was in the church-owners', as well as the clergy's, long-term interests to see the smallholder survive, and it was also imperative that livestock be redistributed. In reference to this last point, when the productivity of church owners' and ecclesiastical land was reduced, it is likely that these landlords lost proportionally fewer livestock than the smallholders around them, whereas many smallholders might have quickly lost so many animals that they ended up with more usable land than they had animals for.

## 9. Volcanic events and their implications

A long-term view of human ecodynamics spans many varied experiences of good times and bad for different communities following various, sometimes divergent, paths with different legacies and junctures of circumstance. With this perspective we may reflect on how human communities may be resilient (or vulnerable) in the face of environmental threats that had either never been encountered before, or had last occurred generations in the past. Was the eventual outcome just a random case of bad luck or are there lessons from the experiences of the past that may help us prepare for an unpredictable future? Environmental threats may be many and varied, but there are comparatively few ways in which they affect people, and responses developed to address one set of vulnerabilities may have multiple benefits. Conversely, vulnerabilities and human insecurities created by society may be realized by a series of different environmental hazards. In key ways, the regional effects of large volcanic eruptions (which occur rarely) may mimic, for example, the impacts of very severe weather, or

prolonged harsh winters (which occur more frequently). Crops fail, livestock may die in very large numbers, and while some grazing areas may be destroyed, most simply become unproductive for a limited number of seasons. As a result, a key determinant of episodic volcanic impact is the prevailing food security. Where food stocks are limited and access to alternative food sources is not possible, then people will die.

The basis for Icelandic resilience to either the direct or indirect effects of volcanic eruptions, or other extreme, unpredictable events, comes through a combination of factors, some of which we could choose to emulate, and others which we should not. A farming system linked to an extensive use of wild resources meant that when farming was under pressure from the impact of volcanic eruptions more wild resources (such as fish, birds and marine mammals) could be taken to make up for shortfalls, although this was dependent upon timing of the crisis as well as the capacity to harvest wild resources. A vulnerability to food shortages could be displaced as alternative resources were consumed, although through this additional hunting and population reduction it could generate other vulnerabilities for later generations. Other spatial and temporal displacements of vulnerabilities created by abrupt crises were possible because networks of trade and exchange spanned regions and extended overseas. Thus it was possible (although not always feasible) for an affected community to reach out to areas unaffected by some scales of realized threat and drawn on resources from other areas. Resilience could be enhanced through the storage of food both in the form of live animals and stored products such as dried fish that could be kept over many years. This, however, required the creation of a food surplus and the means to store or maintain it. Buildings were resistant to the direct impacts of ash fall having been built to cope with loadings from snow, and overland travel by horses rather than wheeled vehicles and paved roads meant that transport links lacked a vulnerable, fixed infrastructure but were still vulnerable to the loss of horses or the creation of impassable conditions. As livestock existed for wool production as well as for meat and milk, they could be systematically reduced in numbers while leaving the potential to rebuild populations. Social capital could be tapped into, to overcome an immediate crisis, but that could displace vulnerability to the future by creating indebtedness. Flexibility of food production and storage, regional support networks, resilient infrastructure and the capacity to rebuild are all strategies that could be adopted today to build the capacity to avoid disasters. A final component of past resilience that is not acceptable today (but which arguably still exists) is the presence of an expendable class. When disaster struck in Iceland and there was insufficient food, social structures created a hierarchy of who would survive and who would not (Vasey, 1996, 2001).

A sobering lesson from the past is that vulnerability may not be eliminated, but simply displaced. This displacement may be to a particular group within society who die in greater number - that could be the old, the poor or the landless. Alternatively, vulnerabilities could be displaced spatially to another region, or temporally to a future generation through the consumption of natural resources. Famine is avoided, but the rangelands are degraded, soils eroded or wild populations reduced.

## 10. The need to integrate social science and humanities more fully in the global change agenda

The World Humanities Report 2015 asserts that the humanities "provide a key to human diversity without which we cannot understand ourselves" (Holm et al., 2015, 189). It should be added that without understanding ourselves — including how we respond to natural and societal challenges — we can hardly expect to make reliable models or predictions of outcomes that require taking human behavior, choices and responses into account.

In the most recent IPCC (2014) assessment the need for humanities and social sciences expertise and perspectives is acknowledged, at least

implicitly: "Effective decision making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty" (IPCC, 2014) (AR5 Summary for Policymakers, 17).

Yet IPCC (2014) stops short of a fuller acknowledgment that meeting such a need may require a recalibration of the prevailing scientific assessment model, including a widening of the community of participating scholars and scientists. At the very least what is needed is a new understanding of the kinds of knowledge that must be inventoried in any assessment of the earth system that presumes to deal with the inherent complexities of the system's human dimensions — the cultural, social, political and economic inputs and outputs that interact with biophysical and geophysical processes and which are central to the phenomena of global change — now, historically, and in the future.

The far-from-common approach to environmental studies highlighted in this paper, encompassing contributions integrated from multiple disciplines in the humanities, social sciences and geosciences, demonstrates one viable model of research organization and execution that can serve to close gaps in knowledge, make accessible new or otherwise unused data and generate new understanding concerning responses to threats of the New Human Condition through a combination of empirical and deductive methods.

## 11. Conclusions

Since the New Human Condition situates human perception and agency at the center of global climate change (to draw on the guest editors' framing of this special issue), the challenges are understood not merely as the externalities of almost-unchanging nature but as crises of culture that imply various possible responses to threats. The aim of the intersecting research projects within the Circumpolar Networks program of IHOPE is to increase scholarly understanding of how human communities have responded in the past to extreme environmental events and variability, and to make this knowledge available for the benefit of human communities in the present and future. Much work remains to be done in this regard. This paper offers an illustration of the kind of comprehensive *integrated* research that can help to enrich the global change research community's findings. Historical, literary, and archaeological study can be applied to good effect to the findings of environmental science (and vice versa). If appropriate efforts are taken to co-design and co-execute integrated studies — and when possible, as in this paper, to co-disseminate their results — new insights into changing human-landscape-environment interactions through time can be achieved. With such an ambition in mind, the following observations regarding long-term human ecodynamics are offered as points ripe for future investigation, particularly if based on the model of integrated environmental studies highlighted in this paper:

- It is possible to identify ways in which past climate change can act as a driver of socioecological stress with a capacity to directly affect people without recourse to a simple (and flawed) climate determinism.
- Climate change does not operate in isolation; prior vulnerabilities created by people determine the scale of impact. Thus the socioecological settings of climate are key to understanding what drivers of change and impacts need to be understood in such a context.
- Data on climate change can be derived from various environmental proxies but they often lack either the very precise resolution (to the season) and/or the spatial proximity to areas of human settlement necessary to know how people have been/can be affected.
- Documentary records and bodies of both normative literature and native (environmentally embedded) storytelling can help to fill this gap by providing preserved insights into Local/Traditional Environmental Knowledge.

- We can use examples from the past to learn how to build (or erode) resilience to climate change.
- Successful adaptations can serve more than one function — resilience to the effects of climate-induced shortages (such as loss of agricultural yields) can help buffer the impacts of other natural threats (e.g. volcanic eruptions) or they may leave some communities more vulnerable to other threats (e.g., as in the case of Norse Greenlanders of the late-thirteenth to early-fourteenth century when whole communities may have been mobilized for the seasonal seal and walrus hunts and made vulnerable in perilous sea conditions due to increased storminess).
- Past global changes have yielded both winners and losers — some human populations or groups lose far more than others and the choices made when attempting to minimize human insecurities and suffering are often stark. It is possible for entire communities to fail (again the example of Norse Greenlanders).
- One focus of research underway within IHOPe CN collaborations is on a marginal set of environments where climate changes in the past have crossed key natural thresholds for agricultural productivity. Future scales of change are likely to cross comparable thresholds within core areas of human activity. Thus past changes can be used to help anticipate the effects of, and possible responses to, future changes.
- Both Iceland and Greenland were connected to mainland polities and markets, but Greenland's economy seems to have been built around what turned into a long-distance seasonal hunt for walrus and other arctic products that in many ways complicated subsistence farming and hunting in the distant settlement areas. Icelandic winter fishing and winter textile production did not present the same scheduling problems, and thus did not conflict with summer subsistence activities. Greenlanders paid a higher price in time, hazard, and travel than the Icelanders and their trading economy created vulnerabilities to multiple hazards. The way global trade connections interact with climate, subsistence economy, and local food securities had considerable impact on the different fates of the two communities.
- The lessons of these two closely related but ultimately very different northern communities have resonance in the modern world, especially in a rapidly changing arctic, issues of global change impacts upon local societies, rapid and destabilizing climate change, and uncertain governance beg more attention than ever. While modern societies are far more powerful and well informed than the medieval Norse, pathway dependence and the attractions of "business as usual" approaches are factors at work as much today as in the past. Modern scenario builders aiming to direct us toward desirable futures, and away from pathways to darker outcomes, can broaden their working knowledge of what is possible through a fuller and more integrated understanding of what has happened in the past.

## Funding

This research was made possible by generous grants from the Icelandic Centre for Research/RANNÍS (award 163133-051), Riksbankens Jubileumsfond: the Swedish Foundation for Humanities and Social Sciences (award F11-1313:1), the National Science Foundation (awards: 0732327; 1140106; 1119354; 1203823; 1203268; 1202692; 1249313; 0527732; 0638897; 0629500; 0947862; 1446308) and NordForsk (awards: 29002; 61841; 76654; 72925); Mid Sweden University Faculty of Human Sciences-funded and Vetenskapsrådet: the Swedish Research Council-funded research time for "Mapping Environmental Consciousness" (award # 421-2007-1929) supported the wider intellectual effort leading to this paper.

## Acknowledgements

The authors would like to thank their colleagues, in particular:

Aaron Kendall; Adolf Friðriksson; Anthony Newton; Árni Daníel Júliusson; Árni Einarsson; Birna Lárusdóttir; Celine Dupont-Hebert; Christian Keller; Christian Koch Madsen; Elisabeth Ida Ward; Emily Lethbridge; Frank Feeley; Gaston Demarée; Garðar Guðmundsson; Gísli Pálsson; Gísli Sigurðsson; Guðrún Nordal; Howell Roberts; Ian Lawson; Ian Simpson; Ingibjörg Jónsdóttir; Ingrid Mainland; James Woollett; Jette Arneborg; Julie Bond; Karen Milek; Konrad Smiarowski; Lilja Pálsdóttir; Mae Kilker; Megan Hicks; Michael Nielsen; Michael Twomey; Mike Church; Niels Einarsson; Orri Vésteinsson; Páll Bergþórsson; Philippa Ascough; Ragnhildur Sigurðardóttir; Ramona Harrison; Richard Streeter; Reinhard Hennig; Seth Brewington; Sigurgeir Steingrímsson; Sjófn Kristjánsdóttir; Steve Dockrill; Þorvarður Árnason; Trausti Jónsson; Vicki Szabo; Viðar Hreinsson; the staff of the Institute of Archaeology, Iceland; colleagues at the Árni Magnússon Institute for Icelandic Studies; and all the many collaborators in North Atlantic research that made this paper possible. We are especially grateful for the kindness and support of our host communities in Iceland and Greenland.

## References

Abu-Lughod, J., 1981. *Before European Hegemony: The World System A.D. 1250–1350*. Oxford University Press, Oxford.

Adderley, W.P., Simpson, I., 2006. Soils and palaeo-climate based evidence for irrigation requirements in Norse Greenland. *J. Archaeol. Sci.* 33 (12), 1666–1679.

Adger, W.N., Lorenzoni, I., O'Brien, K. (Eds.), 2009. *Adapting to Climate Change: Thresholds, Values and Governance*. Cambridge University Press, Cambridge.

Alexandre, P., 1976. *Le Climat au Moyen Age en Belgique et dans les régions voisines (Rhénanie, Nord de la France)*. Publication No. 50 du Centre Belge d'Histoire Rurale, Liège.

Alexandre, P., 1987. Le climat en Europe au Moyen Age, contribution à l'histoire des variations climatiques de 1000 à 1425, d'après les sources narratives de l'Europe occidentale, Editions de l'Ecole des hautes études en sciences sociales. Recherches d'histoire et de sciences sociales, Paris.

Amorosi, T., Buckland, P., Dugmore, A.J., Ingimundarson, J.H., McGovern, T.H., 1997. Raiding the landscape: human impact in the North Atlantic. In: Fitzhugh, W., Hunt, T. (Eds.), *Island Archaeology*, (special edition of *Human Ecology*, 25, 3, 491–518).

Amundsen, C.P., Perdikaris, S., McGovern, T.H., Krivogorskaya, Y., Brown, M., Smiarowski, K., Storni, S., Modugno, S., Frik, M., Koczela, M., 2005. Fishing booths and fishing strategies in medieval Iceland: an archaeofauna from Akurvík, North-West Iceland. *Environ. Archaeol.* 10 (2), 141–198.

AHDR, 2004. In: Einarsson, N., Nyman Larsen, J., Nilsson, A., Young, O.R. (Eds.), *Arctic Human Development Report*. Stefansson Arctic Institute, Akureyri.

AHDR, 2015. In: Nyman Larsen, J., Fondahl, G. (Eds.), *Arctic Human Development Report. Regional Processes and Global Linkages*. Nordic Council of Ministers, Copenhagen.

Arctic Report Card, 2016. <http://www.arctic.noaa.gov/Report-Card/Report-Card-2016> Retrieved 12 March 2017.

Arendt, H., 1998. [1958]. *The Human Condition*. University of Chicago Press, Chicago.

Árna saga biskups, 1972. In: Hauksson, P. (Ed.), (the Saga of Bishop Árni). Stofnun Árna Magnússonar, Reykjavík.

Arnalds, Ó., 1992. Jarðvegsleifar í Óðáðahrauni. In: Arnalds, A. (Ed.), *Græðum Ísland*. Árbók 4. Landgræðsla Ríkissins, Reykjavík, pp. 159–164.

Arneborg, J., 2012. Churches, Christianity, and magnate farmers in the Norse Eastern Settlement. In: Gulløv, H.C., Toft, P.A., Hansgaard, C.P. (Eds.), *Challenges and Solutions: Northern Worlds*. National Museum of Denmark, Copenhagen, pp. 167–170.

Arneborg, J., Nyegaard, G., Vésteinsson, O. (Eds.), 2009. *Norse Greenland: Selected Papers from the Hvalsey Conference 2008*, *Journal of the North Atlantic*, Special Volume 2. Eagle Hill Publications, Steuben.

Human diet and subsistence patterns in Norse Greenland AD c.980–AD c.1450: archaeological interpretations. In: Arneborg, J., Lyneupur, N., Heinemeier, J. (Eds.), *Journal of the North Atlantic*. 3, pp. 94–133.

Batt, C.M., Schmid, M.M.E., Vésteinsson, O., 2015. Constructing chronologies in Viking Age Iceland: increasing dating resolution using Bayesian approaches. *J. Archaeol. Sci.* 62, 164–174.

Bell, W.T., Ogilvie, A.E.J., 1978. Weather compilations as a source of data for the reconstruction of European climate during the medieval period. *Clim. Chang.* 1, 331–348.

Bergþórsson, P., 1967. *Kuldskeið um 1300? Veðrið* 12 (2), 55–58.

Bergþórsson, Páll, 1969. An estimate of drift ice and temperature in Iceland in 1000 years. *Jökull* 19, 95–101.

Blöndal, S., Gunnarsson, S.B., 1999. *Íslandsskógar* (Iceland's Forests). Mál og Mynd, Reykjavík.

Bradley, R.S., Jones, P.D. (Eds.), 1992. *Climate Since A.D. 1500*. Routledge, London and New York.

Bradley, R.S., Hughes, M.K., Diaz, H.F., 2003. Climate in Medieval time. *Science* 302, 404–405.

Bradley, R.S., Wanner, H., Diaz, H.F., 2016. The Medieval Quiet Period. *The Holocene* 26

(6), 990–993. <http://dx.doi.org/10.1177/095963615622552>. (Published online before print January 22, 2016).

Brázdil, R., 1995. *History of Weather and Climate in the Czech lands*, Zürcher geographische Schriften, Heft 62. Verlag Geographisches Institut, Zürich.

Brázdil, R., Pfister, C., Wanner, H., Von Storch, H., Luterbacher, J., 2005. Historical climatology – the state of the art. *Clim. Chang.* 70, 363–430.

Boulhosa, P.P., 2012. Of fish and ships in medieval Iceland. In: Imsen, S. (Ed.), *The Norwegian Domination and the Norse World, c. 1100 – c. 1400*. Tapir Academic Press, Trondheim, pp. 175–198.

Campbell, B., 2016. *The Great Transition: Climate, Disease and Society in the Late-Medieval World*. Cambridge University Press, Cambridge.

Camenisch, C., et al., 2016. The 1430s: a cold period of extraordinary internal climate variability during the early Spörer Minimum with social and economic impacts in north-western and central Europe. *Clim. Past* 12, 2107–2126. <http://dx.doi.org/10.5194/cp-12-2107-2016>.

Casely, A.F., Dugmore, A.J., 2007. Good for glaciers, bad for people? Archaeologically relevant climate models developed from reconstructions of glacier mass balance. *J. Archaeol. Sci.* 34, 1763–1773.

Crumley, C., 2007. Historical ecology: integrated thinking at multiple temporal and spatial scales. In: Hornborg, A., Crumley, C. (Eds.), *The World System and The Earth System: Global Socio-Environmental Change and Sustainability Since the Neolithic*. Left Coast Press, Walnut Creek CA, pp. 15–28.

Crutzen, P.J., Stoermer, E.F., 2000. The Anthropocene. *Global Change Newsletter* 41, 17–18.

Demarée, G.R., Ogilvie, A.E.J., 2001. *Bon baisers d'Islande: climatological, environmental and human dimensions impacts in Europe of the Lakiagígar eruption (1783–1784) in Iceland*. In: Jones, P.D., Ogilvie, A.E.J., Davies, T.D., Briffa, K.R. (Eds.), *History and Climate: Memories of the Future?* Kluwer Academic/Plenum Publishers New York, Boston, Dordrecht, London, Moscow, pp. 219–246.

d'Entreves, M.P., 2014. In: Zalta, Edward N. (Ed.), "Hannah Arendt", The Stanford Encyclopedia of Philosophy (Summer 2014 Edition). <http://plato.stanford.edu/archives/sum2014/entries/arendt/> (Retrieved 1 March 2017).

Diamond, J.M., 2005. *Collapse. How Societies Choose to Fail or Survive*. Viking, New York.

Diaz, H.F., Trigo, R., Hughes, M., Mann, M.E., Xoplaki, E., Barriopedro, D., 2011. Spatial and temporal characteristics of climate in medieval times revisited. *Bulletin of the American Meteorological Society*. <http://dx.doi.org/10.1175/BAMS-D-10-05003.1> (Published Online: 1 November 2011).

Dickson, R.R., Meincke, J., Malmberg, S.-Å., Lee, A.J., 1988. The "great salinity anomaly" in the northern North Atlantic 1968–1982. *Prog. Oceanogr.* 20, 103–151.

Diplomatarium Islandicum, 1893. *Íslenskt Fornríðasafn*, Vol. II (1253–1350). Hið íslenska bókmenntafélag, Copenhagen.

Dugmore, A.J., Erskine, C.C., 1994. Local and regional patterns of soil erosion in southern Iceland. *Münchener Geographische Abhandlungen* B12, 63–79.

Dugmore, A.J., Vesteinsson, O., 2012. Black sun, high flame, and flood: volcanic hazards in Iceland. In: Cooper, J., Sheets, P. (Eds.), *Surviving Sudden Environmental Change Answers From Archaeology*. Univ. Press of Colorado, Boulder, CO, pp. 67–90.

Dugmore, A.J., Buckland, P.C., Church, M.J., Edwards, K.J., Lawson, I., McGovern, T.H., Panagiotakopulu, E., Simpson, I.A., Skidmore, P., Sveinbjarnardóttir, G., 2005. The Norse landnám on the North Atlantic islands: an environmental impact assessment. *Polar Record* 41 (216), 21–37.

Dugmore, A.J., Church, M.J., Mairs, K.A., McGovern, T.H., Newton, A.J., Sveinbjarnardóttir, G., 2006. An over-optimistic pioneer fringe? Environmental perspectives on medieval settlement abandonment in Thorsmork, south Iceland. In: Arneborg, J., Grønnow, B. (Eds.), *The Dynamics of Northern Societies*. PNM, Publications from the National Museum, Copenhagen, pp. 333–344 *Studies in Archaeology and History*, 10.

Dugmore, A.J., Keller, C., McGovern, T.H., 2007. Norse Greenland settlement: reflections on climate change, trade, and the contrasting fates of human settlements in the North Atlantic Islands. *Arct. Anthropol.* 44 (1), 12–36.

Dugmore, A.J., Gísladóttir, G., Simpson, I.A., Newton, A.J., 2009. Conceptual models of 1,200 years of Icelandic soil erosion reconstructed using tephrochronology. *Journal of the North Atlantic* 2, 1–18.

Dugmore, A.J., McGovern, T.H., Vésteinsson, O., Arneborg, J., Streeter, R., Keller, C., 2012. Cultural adaptation, compounding vulnerabilities conjunctures in Norse Greenland. *Proceedings of the National Academy of Sciences of the United States of America* 109 (10), 3658–3663.

Dugmore, A.J., McGovern, T.H., Streeter, R., Madsen, C.K., Smiarowski, K., Keller, C., 2013. 'Clumsy solutions' and 'elegant failures': lessons on climate change adaptation from the settlement of the North Atlantic islands. In: Sygna, L., O'Brien, K., Wolf, J. (Eds.), *A Changing Environment for Human Security: Transformative Approaches to Research, Policy and Action*. Routledge, Abingdon and New York, pp. 435–451.

Dugmore, A.J., McGovern, T.H., Streeter, R., 2014. Landscape legacies of Landnám in Iceland: what has happened to the environment as a result of settlement, why did it happen and what have been some of the consequences. In: Harrison, R., Mather, R., R. (Eds.), *Human Ecodynamics in the North Atlantic: A Collaborative Model of Humans and Nature Through Space and Time*. Lexington Books, New York, pp. 195–211.

Einarsson, Th., 1994. *The Geology of Iceland: Rocks and Landscape*. Mál og Menning, Reykjavík.

Enghoff, I.B., 2003. Hunting, fishing, and animal husbandry at the Farm Beneath the Sand, Western Greenland: an archaeozoological analysis of a Norse farm in the Western Settlement. *Meddelelser om Grønland. Man and Society* 28 (Copenhagen).

Frei, K.M., Couto, A.N., Smiarowski, K., Harrison, R., Madsen, C.K., Arneborg, J., Frei, R., Guðmundsson, G., Sindbæk, S.M., Woollett, J., Hartman, S., Hicks, M., McGovern, T.H., 2015. Was it for walrus? Viking Age settlement and medieval walrus ivory trade in Iceland and Greenland. *World Archaeol.* 47 (3), 439–466.

Garcia-Herrera, R., Barriopedro, D., Hernández, E., Diaz, H.F., Garcia, R.R., Prieto, M.R., Moyano, R., 2008. A chronology of El Niño Events from Primary Documentary Sources in Northern Peru. *J. Climate*. <http://dx.doi.org/10.1175/2007JCLI1830.1> (Retrieved 26 February 2017).

Grágás, 2001. In: Karlsson, G., Sveinsson, K., Árnason, M. (Eds.), *Lagasafn íslenska þjóðveldisins. Mál og menning*. Reykjavík.

Guðmundur saga Arasonar. Vigfússon, G., Sigurðsson, J., (Eds.), 1856–78. *(The Saga of Bishop Guðmundur Arason)* in *Biskupa Sögur I-II*. Hinu Íslenska Bókmentafélagi, Copenhagen.

Guðmundsson, H.J., 1997. A review of the Holocene environmental history of Iceland. *Quat. Sci. Rev.* 16, 81–92.

Guðmundsson, M.T., Larsen, G., Höskuldsson, A., Gylfason, Á.G., 2008. Volcanic hazards in Iceland. *Jökull* 58, 251–268.

Hambrecht, G., 2015. The first European colonization of the North Atlantic. In: Leone, M., Knauf, J. (Eds.), *Historical Archaeologies of Capitalism*. Springer, New York, pp. 203–225.

Harington, C.R. (Ed.), 1992. *The Year Without a Summer? World Climate in 1816*. Canadian Museum of Nature, Ottawa.

Harrison, R., 2013. *World Systems and Human Ecodynamics in Medieval Eyjafjörður, North Iceland: Gásir and Its Hinterlands*. Unpublished Ph.D. dissertation Hunter College, CUNY.

Harrison, R., 2014a. Gásir archaeology–international exchange and Eyjafjörður ecodynamics in Medieval Iceland. In: Harrison, R., Maher, R. (Eds.), *Long-term Human Ecodynamics in the North Atlantic: An Archaeological Study*. Lexington Publishers, Lanham, Maryland, pp. 10–35.

Harrison, R., 2014b. Connecting the land to the sea at Gásir. In: Harrison, R., Maher, R. (Eds.), *Long-term Human Ecodynamics in the North Atlantic: An Archaeological Study*. Lexington Publishers, Lanham, Maryland, pp. 117–136.

Hartman, S., 2015. Unpacking the Black Box: The Need for Integrated Environmental Humanities. *Future Earth Blog*. (3 June 2015).

Hartman, S., 2016. Revealing Environmental Memory: what the study of medieval literature can tell us about long-term environmental change. *Biodiverse* 2(2016) (*Biodiverse* 2016-07-01 Nr 2 2016 (<http://www.biodiverse.se/number/nr-2-2016-arg-21/>) CBM Swedish Biodiversity Centre, SLU/Uppsala University, Sweden).

Hartman, S., Ogilvie, A.E.J., Hennig, R., 2016. "Viking" ecologies: Icelandic sagas, local knowledge, and environmental memory. In: Parham, J., Westling, L. (Eds.), *A Global History of Literature and the Environment*. Cambridge University Press, Cambridge, pp. 125–140.

Halldórsson, Ó., 1978. *Grænland í Miðaldaritum*. Sögufélag, Reykjavík.

Hayeur-Smith, M., 2011. Preliminary Textile Report: Möðruvellir, Iceland, *Research Reports of the Circumpolar Lab* 3. Haffenreffer Museum of Anthropology, Brown University, Providence, Rhode Island.

Hayeur-Smith, M., 2013. Dress, cloth, and the farmer's wife: textiles from Ø 172 Tatsipataakilleq Greenland with comparative data from Iceland. *Journal of the North Atlantic* 6, 64–81.

Henriksen, N., Higgins, A.K., Kalsbeek, F., Pulvertaft, T.C.R., 2009. Greenland from Archaean to Quaternary. Descriptive Text to the 1995 Geological map of Greenland, 1:2 500 000, second ed. Geological Survey of Denmark and Greenland Bulletin 18 (Copenhagen).

Hoffmann, R.C., 2014. *An Environmental History of Medieval Europe*. Cambridge Medieval Textbooks. Cambridge University Press.

Holm, P., Scott, D., Jarrick, A., 2015. *Humanities World Report 2015*. Palgrave Macmillan, Houndsmill, Basingstoke, UK and New York, NY.

Holtsmark, A., 1956. Kongespeilitteratur. *Kulturhistorisk Leksikon for Nordisk Middelalder* 9. Rosenkilde og Bagger, Copenhagen (col. 61–68).

Hreinsson, V. (Ed.), 1997. *The Sagas of Icelanders*. Vols. I–V Leifur Eiriksson Press, Reykjavík.

Hughes, M.K., Diaz, H.F., 1994. Was there a 'Medieval Warm Period', and if so, where and when? *Clim. Chang.* 26, 109–142.

Human Development Report 2015, 2015. *Work For Human Development*. <http://report.hdr.undp.org> (Retrieved 25 January 2017).

Ingimundarson, J.H., 1995. Of Sagas and Sheep: Toward a Historical Anthropology of Social Change and Production for Market, Subsistence and Tribute in Early Iceland (10th to the 13th Century). Unpublished PhD thesis University of Arizona, Tucson, Arizona.

Ingimundarson, J.H., 2010. Comparative-historical analysis of farming systems and agricultural intensification in medieval and early modern Iceland. In: Winther, G., Rasmussen, R.O. (Eds.), *Political Economy of Northern Regional Development*. Nordi Council of Ministers, TemaNord, Copenhagen, pp. 321–338.

Ingimundarson, J.H., Ogilvie, A.E.J., 1998a. Climatic change, socio-economic transformation, and ecological succession in the late twelfth to fourteenth century in Iceland. In: 28th Arctic Workshop, Arctic and Alpine Environments, Past and Present, Program with Abstracts. 80 INSTaar, Boulder, Colorado.

Ingimundarson, J.H., Ogilvie, A.E.J., 1998b. Economic transformations, climatic thresholds, and ecological succession in medieval Iceland. In: Abstracts, American Anthropological Association, 97th Annual Meeting, 2–6 December 1998, Philadelphia, pp. 241.

Ingram, M.J., Underhill, D.J., Wigley, T.M.L., 1978. Historical climatology. *Nature* 276, 329–334.

Ingram, M.J., Farmer, G., Wigley, T.M.L., 1981. Past climates and their impact on man: a review. In: Wigley, T.M.L., Ingram, M.J., Farmer, G. (Eds.), *Climate and History: Studies in Past Climates and their Impact on Man*. Cambridge University Press, Cambridge.

IPCC, 2014. *Climate Change 2014*. In: Pachauri, R.K., Meyer, L.A. (Eds.), *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland.

Jóhannesson, J., 1956. Íslendinga saga I Þjóðveldisöldin. Almenna bókafélagið, Reykjavík.

Jóhannesson, J., 1974. *A History of the Old Icelandic Commonwealth*. Íslendingasaga. Bessason, H. (Trans.). University of Manitoba Press, Winnipeg.

Jóhannesson, P., 1928. Um atvinnu og fjárhagi á Íslandi á 14. og 15. öld. Vaka 2, 17–53.

Jones, P.D., 2008. Historical climatology - a state of the art review. *Weather* 63 (7), 181–186.

Jones, P.D., Mann, M.E., 2004. Climate over past millennia. *Reviews of Geophysics* 42. <http://dx.doi.org/10.1029/2003RG000143>.

Jones, P.D., Ogilvie, A.E.J., Davies, T.D., Briffa, K.B. (Eds.), 2001. *History and Climate: Memories of the Future?* Kluwer Academic/Plenum Publishers, New York, Boston, Dordrecht, London, Moscow.

Jónsbók, 2004. In: Jónsson, M. (Ed.), *Lögbók Íslendinga hver sampykkt var á alþingi árið 1281 og endurnýjuð um miðja 14. öld en fyrst prentuð árið 1587*. Háskólaútgáfan, Reykjavík.

Karlsson, G., 2000. Iceland's 1100 years: History of a Marginal Society. Mál og Menning, Reykjavík.

Kristjánsson, Luðvík, 1980. *Íslenskir sjávarhættir 1*. Bókaútgáfa Menningarsjóðs, Reykjavík.

Kirkbride, M.P., Dugmore, A.J., 2008. Two millennia of glacier advances from southern Iceland dated by tephrochronology. *Quat. Res.* 70, 398–411.

Lamb, H.H., 1965. The early medieval warm epoch and its sequel. *Palaeogeography, Palaeoclimatology, Palaeoecology* 1, 13–37.

Larsen, L.M., 1917. *The King's Mirror (Speculum Regale-Konungs Skuggsjá)*. Scandinavian Monographs 3. The American Scandinavian Foundation, New York.

Laurentius saga biskups, 1969. In: Björnsson, A. (Ed.), (The Saga of Bishop Laurentius). Rit Handritastofnunar Íslands III, Reykjavík.

Le Roy Ladurie, E., 1972. *Times of Feast, Times of Famine: A History of Climate Since the Year 1000*. George Allen and Unwin, London.

Ludlow, F., 2010. The Utility of the Irish Annals as a Source for the Reconstruction of Climate. Unpublished PhD Thesis submitted to the University of Dublin, Trinity College, Ireland.

Luterbacher, J., et al., 2016. European summer temperatures since Roman times. *Environ. Res. Lett.* 11. <http://dx.doi.org/10.1088/1748-9326/11/2/024001>.

Madsen, C.K., 2014. *Pastoral Settlement, Farming, and Hierarchy in Norse Vatnahverfi, South Greenland*. Unpublished PhD thesis University of Copenhagen, Denmark. <http://www.nabohome.org/postgraduates/theses/ckm/>.

Martin-Vide, J., Barriendos, M., 1995. The use of rogation ceremony records in climatic reconstruction: a case study from Catalonia (Spain). *Clim. Chang.* 30, 201–221.

Mauelshagen, F., 2014. Redefining historical climatology in the Anthropocene. *Anthropocene Review* 1 (2), 171–204. <http://dx.doi.org/10.1177/2053019614536145>.

McGovern, T.H., 1985a. Contributions to the paleoeconomy of Norse Greenland. *Acta Archaeologica* 54, 73–122.

McGovern, T.H., 1985b. The arctic frontier of Norse Greenland. In: Green, S., Perlman, S. (Eds.), *The Archaeology of Frontiers and Boundaries*. Academic Press, New York, pp. 275–323.

McGovern, T.H., Bigelow, G.F., Amorosi, T., Russell, D., 1988. Northern islands, human error, and environmental degradation: a preliminary model for social and ecological change in the medieval North Atlantic. *Human Ecology* 16 (3), 45–105.

McGovern, T.H., Amorosi, T., Perdikaris, S., Woollett, J.W., 1996. Zooarchaeology of Sandnes V51: economic change at a chieftain's farm in West Greenland. *Arct. Anthropol.* 33 (2), 94–122.

McGovern, T.H., Perdikaris, S., Einarsson, Á., Sidell, J., 2006. Coastal connections, local fishing, and sustainable egg harvesting, patterns of Viking age inland wild resource use in Mývatn district, northern Iceland. *Environ. Archaeol.* 11 (1), 102–128.

McGovern, T.H., Vésteinsson, O., Friðriksson, A., Church, M.J., Lawson, I.T., Simpson, I.A., Einarsson, Á., Dugmore, A.J., Cook, A.J., Perdikaris, S., Edwards, K., Thomson, A.M., Adderley, P.W., Newton, A.J., Lucas, G., Edvardsson, R., Aldred, O., Dunbar, E., 2007. Landscapes of settlement in northern Iceland: Historical Ecology of human impact and climate fluctuation on the millennial scale. *Am. Anthropol.* 109 (1), 27–51.

McGovern, T.H., Perdikaris, S., Mainland, I., Ascough, P., Ewens, V., Einarsson, Á., Sidell, J., Hambrecht, G., Harrison, R., 2009. The archaeofauna. In: Lucas, G. (Ed.), *Hofstadir: Excavations of a Viking Age Feasting Hall in North Eastern Iceland*. Inst. of Archaeology Reykjavík, Reykjavík, pp. 168–252 Monograph 1.

McGovern, T.H., Smiarowski, K., Harrison, R., 2013. *Hard times at Hofstadir: an archaeofauna ca AD 1300 from Hofstadir Myvatnssveit N Iceland*, NABO/NOREC Laboratory Report. 60, 1–28.

McGovern, T.H., Harrison, R., Smiarowski, K., 2014. Sorting sheep and goats in medieval Iceland and Greenland: Local subsistence or world system? In: Harrison, R., Maher, R. (Eds.), *Human Ecodynamics in the North Atlantic: A Collaborative Model of Humans and Nature through Space and Time*. Lexington Publishers, Lanham, Maryland, pp. 153–176.

McTurk, R. (Ed.), 2004. *A Companion to Old Norse-Icelandic Literature and Culture*. Blackwell Publishing, Oxford.

Miles, M.W., Divine, D.V., Furevik, T., Jansen, E., Moros, M., Ogilvie, A.E.J., 2014. A signal of persistent Atlantic multidecadal variability in Arctic sea ice. *Geophys. Res. Lett.* 41. <http://dx.doi.org/10.1002/2013GL058084>.

Miller, G.H., Geirsdóttir, Á., Zhong, Y., Larsen, D.J., Otto-Biesner, B.L., Holland, M.M., Bailey, D.A., Refsnider, K., Lehman, S., Souton, J., Anderson, C., Björnsson, H., Thordarson, T., 2012. Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks. *Geophys. Res. Lett.* 39 (2), L02708. <http://dx.doi.org/10.1029/2011GL050168>.

Nelson, M.C., Ingram, S.E., Dugmore, A.J., Streeter, R., Peeples, M.A., McGovern, T.H., Hegmon, M., Arneborg, J., Kintigh, K.W., Brewington, B., Spielmann, K.A., Simpson, I.A., Strawhacker, C., Comeau, L.E.L., Torvinen, A., Madsen, C.K., George Hambrecht, G., Smiarowski, K., 2015. Climate challenges, vulnerabilities, and food security. *Proceedings of the National Academy of Sciences of the United States of America* 1–6. [www.pnas.org/cgi/doi/10.1073/pnas.1506494112](http://www.pnas.org/cgi/doi/10.1073/pnas.1506494112).

OECD, 2015. *OECD Economic Surveys: Iceland 2015*. OECD Publishing, Paris.

Ogilvie, A.E.J., 1982. Climate and Society in Iceland from the Medieval Period to the Late Eighteenth Century. Unpublished PhD thesis School of Environmental Sciences, University of East Anglia, Norwich, UK.

Ogilvie, A.E.J., 1984. The past climate and sea-ice record from Iceland. Part 1: data to A.D. 1780. *Clim. Chang.* 6, 131–152.

Ogilvie, A.E.J., 1986. The climate of Iceland, 1701–1784. *Jökull* 36, 57–73.

Ogilvie, A.E.J., 1991. Climatic changes in Iceland AD. c. 865 to 1598. In: Bigelow, G.F. (Ed.), *The Norse of the North Atlantic, Acta Archaeologica*. Vol. 61. Munksgaard, Copenhagen, pp. 233–251.

Ogilvie, A.E.J., 1992. Documentary evidence for changes in the climate of Iceland, A.D. 1500 to 1800. In: Bradley, R.S., Jones, P.D. (Eds.), *Climate Since A.D. 1500*. Routledge, London and New York, pp. 92–117.

Ogilvie, A.E.J., 1998. Historical accounts of weather events and related matters in Iceland and Greenland, A.D. c. 1250 to 1430. In: Frenzel, B. (Ed.), *Documentary Climatic Evidence for 1750–1850 and the 14th century*. Paläoklimaforschung, 23, Special Issue: ESF Project “European Palaeoclimate and Man” 15. European Science Foundation, Strasbourg, Akademie der Wissenschaften und der Literatur, Mainz, pp. 25–43.

Ogilvie, A.E.J., 2001. Climate and farming in northern Iceland, ca. 1700–1850. In: Sigurðsson, I., Skaptason, J. (Eds.), *Aspects of Arctic and Sub-Arctic History*. University of Iceland Press, Reykjavík, pp. 289–299.

Ogilvie, A.E.J., 2005. Local knowledge and travellers' tales: a selection of climatic observations in Iceland. In: Caseldine, C., Russell, A., Harðardóttir, J., Knudsen, O. (Eds.), *Iceland—Modern Processes and Past Environments. Developments in Quaternary Science* 5 Elsevier, Amsterdam-Boston-Heidelberg-London, pp. 257–287 Series Editor Jim Rose.

Ogilvie, A.E.J., 2008. Bréf sýslumannna til stiftamtmanns og amtmanns: environmental images of nineteenth-century Iceland from official letters written by district sheriffs. In: Wells, M. (Ed.), *The Discovery of Nineteenth-Century Scandinavia*. Norvik Press, Norwich, pp. 43–56.

Ogilvie, A.E.J., 2010. Historical climatology, climatic change, and implications for climate science in the 21st century. *Clim. Chang.* 100, 33–47.

Ogilvie, A.E.J., Farmer, G., 1997. Documenting the medieval climate. In: Hulme, M., Barrow, E. (Eds.), *Climates of the British Isles*. Routledge, London and New York, pp. 112–133.

Ogilvie, A.E.J., Jónsson, T., 2001a. “Little Ice Age” research: a perspective from Iceland. *Clim. Chang.* 48, 9–52.

Ogilvie, A.E.J., Jónsson, T. (Eds.), 2001. *The Iceberg in the Mist: Northern Research in Pursuit of a “Little Ice Age”*. Kluwer Academic Publishers, Dordrecht (Reprinted from *Climatic Change* 48) (2001).

Ogilvie, A.E.J., Woollett, J.M., Smiarowski, K., Arneborg, J., Troelstra, S., Pálsdóttir, A., McGovern, T.H., 2009. Seals and sea ice in medieval Greenland. *Journal of the North Atlantic* 2, 60–80.

Páls saga biskups, 1954. In: Sveinsson, E.L. (Ed.), (The Saga of Bishop Páll). Skálholtsfélagið, Reykjavík.

Perdikaris, S., McGovern, T.H., 2008a. Codfish and kings, seals and subsistence: Norse marine resource use in the North Atlantic. In: Torben Rick, T., Erlandson, J. (Eds.), *Human Impacts on Marine Environments*. UCLA Press Historical Ecology Series, Oakland, CApp. 157–190.

Perdikaris, S., McGovern, T.H., 2008b. Viking age economics and the origins of commercial cod fisheries in the North Atlantic. In: Sickling, L., Abreu-Ferreira, D. (Eds.), *The North Atlantic Fisheries in the Middle Ages and Early Modern Period: Interdisciplinary Approaches in History, Archaeology, and Biology*. Brill Publishers, Netherlands, pp. 61–90.

Pfister, C., Brázdil, R., 1992. Monthly temperature and precipitation in central Europe 1525–1979: quantifying documentary evidence on weather and its effects. In: Bradley, R.S., Jones, P.D. (Eds.), *Climate Since A.D. 1500*. Routledge, London and New York, pp. 118–142.

Pfister, C., Luterbacher, J., Schwartz-Zanetti, G., Wegmann, M., 1998. Winter air temperature variations in Western Europe during the early and middle ages (AD 750–1300). *The Holocene* 8, 535–552.

Climatic variability in sixteenth-century Europe and its social dimension: a synthesis. In: Pfister, C., Brázdil, R., Glaser, R. (Eds.), *Clim. Chang.* 43, pp. 5–53.

Pfister, C., Brázdil, R., Luterbacher, J., Ogilvie, A.E.J., White, S., 2017. Early Modern Europe. In: White, S., Pfister, C., Mauelshagen, F. (Eds.), *The Palgrave Handbook of Climate History*. Palgrave Macmillan (eBook ISBN 978-1-137-43020-5; Hardcover ISBN 978-1-137-43019-9 (in press)).

Pierce, E., 2009. Walrus hunting and the ivory trade in early Iceland. *Archaeologia Islandica* 7, 55–63.

Pribyl, K., Cornes, R.C., Pfister, C., 2012. Reconstructing medieval April–July mean temperatures in East Anglia, 1256–1431. *Clim. Chang.* 113, 393–412.

Serreze, M., Stroeve, J., 2015. Arctic sea ice trends, variability and implications for seasonal forecasting. *Phil. Trans. R. Soc. A* 373, 20140159. <http://dx.doi.org/10.1098/rsta.2014.0159>.

Sigurðsson, G., 2004. *The Medieval Icelandic Saga and Oral Tradition: A Discourse on Method*. Center for Hellenic Studies, Harvard University Press, Cambridge, MA.

Simpson, I.A., Dugmore, A.J., Vésteinsson, O., 2001. Crossing the thresholds: human ecology and historical patterns of landscape degradation. *Catena* 42, 175–192.

Smiarowski, K., 2012. *E172 Tatsip Ataa Midden Excavation: 2009 and 2010*. Preliminary Excavation Report. NABO Field Reports. CUNY, New York.

Smiarowski, K., 2014. Climate related farm-to-shieling transition at E74 Qorlortorsuaq

Norse Greenland. In: Harrison, R., Maher, R. (Eds.), *Long-term Human Ecodynamics in the North Atlantic: An Archaeological Study*. Lexington Publishers, Lanham, Maryland, pp. 177–194.

Smiarowski, K., Harrison, R., Brewington, S., Hicks, M., Feeley, F., Dupont-Herbert, C., Hambrecht, G., Woollett, J., McGovern, T.H., 2017. Zooarchaeology of the Scandinavian Settlements in Iceland and Greenland: Diverging Pathways. *Oxford Handbook of Zooarchaeology*. (in press).

Stern, D.V., 2000. *A Hertfordshire Demesne of Westminster Abbey: Profits, Productivity and Weather*. Studies in Regional and Local History. Vol. I University of Hertfordshire Press, Hatfield.

Stine, S., 1994. Extreme and persistent drought in California and Patagonia during mediaeval time. *Nature* 369, 546–549.

Storm, G. (Ed.), 1977. *Islandske Annaler Indtil 1578*. Udgivne for det norske historiske kildeskriktfond, (First published Christiania, 1888. Reprinted Oslo, 1977) (1977).

Storå, J., Lõugas, L., 2005. Human exploitation and history of seals in the Baltic during the Late Holocene. In: Monks, G.G. (Ed.), *The Exploitation and Cultural Importance of Sea Mammals*. Oxbow Books, Oxford, pp. 95–106.

Streeter, R.T., Dugmore, A.J., Vésteinsson, O., 2012. Plague and landscape resilience in premodern Iceland. *Proc. Natl. Acad. Sci.* 109 (10), 3664–3669.

Streeter, R.T., Dugmore, A.J., 2014. Late-Holocene land surface change in a coupled social-ecological system, southern Iceland: a cross-scale tephrochronology approach. *Quat. Sci. Rev.* 86, 99–114.

Streeter, R.T., Dugmore, A.J., Lawson, I.T., Erlendsson, E., Edwards, K.J., 2015. The onset of the palaeoanthropocene in Iceland: changes in complex natural systems. *The Holocene* 25 (10), 1662–1675.

Sturlunga Saga I-II, 1970. 1974 Translated From the Old Icelandic by Julia H. McGrew and R. Thomas, The Library of Scandinavian Literature. Vols 9–10 Twayne Publishers, New York.

Teitsson, B., 1975. Bjarnfeldir í málögum. In: Teitsson, B., Tómasson, S., Thorsteinsson, B. (Eds.), *Afmælisrit Björns Sigfússonar. Sögufélag, Reykjavík*.

Thórarinsson, S., 1944. Tefrokronologiska studier på Island. *Geogr. Ann.* 26, 1–217.

Thórarinsson, S., 1956. The Thousand Years Struggle against Fire and Ice. *Bókaútgáfa Menningarsjóðs, Reykjavík*.

Thórarinsson, S., 1958. *The Öraefajökull Eruption of 1362*, Reykjavík.

Thórarinsson, S., 1967. The Eruptions of Hekla in Historical Times. The Eruption of Hekla 1947–1948. 1. Sögufélag, Reykjavík, pp. 1–170.

Thordarson, T., Self, S., 1993. The Laki (Skaftár Fires) and Grímsvötn eruptions in 1783–1785. *Bull. Volcanol.* 55, 233–263.

Thordarson, T., Larsen, G., 2007. Volcanism in Iceland in historical time: volcano types, eruption styles and eruptive history. *J. Geodyn.* 43, 118–152.

Borláksson, H., 1991. Váfmál og verðlag: Váfmál í utanlandsviðskiptum og búskap Íslendinga á 13. og 14. öld. *Fjölföldun Sigurjóns, Reykjavík*.

Thoroddsen, P., 1914. Islands Klíma í Oldtiden. *Geografisk Tidskrift* 22, 204–216.

Thoroddsen, P., Árferði á Íslandi í písund ár. (The Seasons in Iceland in 1000 Years) Þórvídalur Thoroddsen safnaði og samdi, 1916–17, Gefið út af hínú íslenzka Fræðafelagi í Kaupmannahöfn, (Copenhagen).

Thoroddsen, P., 1919. *Lýsing Íslands: Landbúnaður á Íslandi* I. Hið Íslenzka bókmennafélag, Copenhagen.

Borsteinsson, B., Grímsdóttir, G.Á., 1989. Norska Öldin. In: Líndal, S. (Ed.), *Saga Íslands IV. Sögufélagið, Reykjavík*, pp. 61–258.

Trigg, H., Bolender, D., Johnson, K., Patalano, M., Steinberg, J., 2009. Note on barley found in dung in the lowest levels of the farm mound didden at Reynistadur, Skagafjordur Iceland. *Archaeologia Islandica* 7, 64–72.

van Engelen, A.F.V., Buisman, J., IJnsen, F., 2001. A millennium of weather, winds and water in the low countries. In: Jones, P.D., Ogilvie, A.E.J., Davies, T.D., Briffa, K.R. (Eds.), *History and Climate: Memories of the Future*. Kluwer Academic/Plenum Publishers, New York, N.Y, pp. 101–124.

Vasey, D.E., 1996. Population regulation, ecology, and political economy in preindustrial Iceland. *Am. Ethnol.* 23 (2), 366–392.

Vasey, D.E., 2001. A quantitative assessment of buffers among temperature variations, livestock, and the human population of Iceland, 1784 to 1900. In: Ogilvie, A.E.J., Jónsson, T. (Eds.), *The Iceberg in the Mist: Northern Research in Pursuit of a Little Ice Age*. Kluwer Academic Publishers, Dordrecht, pp. 243–263 (Reprinted from *Climatic Change*, 48, 1) (2001).

Vésteinsson, O., 2007. A divided society. Peasants and the aristocracy in medieval Iceland. *Viking and Medieval Scandinavia* 3, 117–139.

Vésteinsson, O., 2010. Ethnicity and class in settlement period Iceland. In: Sheehan, J., ÓCorráin, D. (Eds.), *The Viking Age: Ireland and the West. Papers from the Proceedings of the Fifteenth Viking Congress*, Cork, 18–27 August 2005. Four Courts Press, Dublin, pp. 494–510.

Vésteinsson, O., 2016. Commercial fishing and the political economy of medieval Iceland. In: Barrett, J., Orton, D. (Eds.), *Cod and Herring: The Archaeology and History of Medieval Sea Fishing*. Oxbow Books, Oxford, pp. 178–195.

Vésteinsson, O., Church, M., Dugmore, A.J., McGovern, T.H., Newton, A.J., 2014. Expensive errors or rational choices: the pioneer fringe in Late Viking Age Iceland. *European Journal of Postclassical Archaeology* 4, 39–68.

Vilmundarson, P., 1972. Evaluation of historical sources on sea ice near Iceland. In: Karlsson, T. (Ed.), *Sea Ice, Proceedings of an International Conference*. National Research Council, Reykjavík.

Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Galuszka, A., Cearreta, A., Edgeworth, M., Ellis, E.C., Ellis, M., Jeandel, C., Leinfelder, R., McNeill, J.R., deB Richter, D., Steffen, W., Svyitski, J., Vidas, D., Wagreich, M., Williams, M., Zhisheng, A., Grinevald, J., Odada, E., Oreskes, N., Wolfe, A.P., 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* 351, 6269.

Wheeler, D., Suarez-Dominguez, J., 2006. Climatic reconstructions for the northeast Atlantic region AD1685–1700: a new source of evidence from naval logbooks. *The Holocene* 16, 39–49.

White, S., Pfister, C., Mauelshagen, F. (Eds.), 2017. *The Palgrave Handbook of Climate History*. Palgrave Macmillan (eBook ISBN 978-1-137-43020-5; Hardcover ISBN 978-1-137-43019-9 (in press)).

Wigley, T.M.L., Ingram, M.J., Farmer, G. (Eds.), 1981. *Climate and History: Studies in Past Climates and their Impact on Man*. Cambridge University Press, Cambridge.

Young, N.E., Schweinsberg, A.D., Briner, J.P., Schaefer, J.M., 2015. Glacier maxima in Baffin Bay during the Medieval Warm Period coeval with Norse settlement. *Sci. Adv.* 1 (11), e1500806. <http://dx.doi.org/10.1126/sciadv.1500806>. (Published online 2015 Dec 4).