Seals and Sea Ice in Medieval Greenland

A.E.J. Ogilvie[1], J. M. Woollett[2], K. Smiarowski[3], J. Arneborg[4], S. Troelstra[5], A. Kuijpers[6], Albína Pálsdóttir[7] and T.H. McGovern[8]

[1]INSTAAR, University of Colorado, Campus Box 450, Boulder, Colorado, 80309-0450, USA
[2]Université Laval, Québec, Canada G1K 7P4G
[3 7 8]Hunter College, CUNY, 695 Park Ave, NY, NY 10065
[4] National Museum of Denmark, Danish Middle Ages and Renaissance, Frederiksholms Kanal 12, DK-1220 København K, Denmark
[5] Department of Paleoclimatology and Geomorphology, Vrije Universiteit, Amsterdam De Boelelaan 1085, 1081HV Amsterdam, the Netherlands
[6] De Nationale Geologiske Undersøgelser for Danmark og Grønland, Øster Voldgade 10, DK-1350 København K, Denmark

Abstract - Multidisciplinary approaches are used to examine possible changes in North Atlantic sea-ice cover, in the context of seal hunting, during the period of the Norse occupation of Greenland (ca. 985-1500). Information from Iceland is also used in order to amplify and illuminate the situation in Greenland. Data are drawn mainly from zooarchaeological analyses, but written records of climate and sea-ice variations, as well as palaeoclimatic data sets are also discussed. Although it should be noted that any use of seal bones from excavated archaeofauna (animal bone collections from archaeological sites) must recognize the filtering effects of past human economic organization, technology, and seal-hunting strategies, it is suggested that differing biological requirements of the six seal species most commonly found in Arctic/North Atlantic regions may provide a potential proxy for past climate, in particular sea-ice conditions. It is concluded that an increase in the taking of harp seals, as opposed to common seals, in the Norse Greenland "Eastern Settlement" in the late-fourteenth century, may reflect an increase in summer drift ice.

Key Words: Greenland; Iceland; North Atlantic; Sea Ice; Seal Biogeography, Zooarchaeology

Introduction: Transitions and Thresholds

> *It is claimed that there are all sorts of seals, too, in those seas, and that they have a habit of following the ice, as if abundant food would never be wanting there.* (Larsen trans. 1917, *The King's Mirror-Speculum Regale-Konungs Skuggsjá: 139*.)

Both humans and marine mammals have an intricate and complex relationship with sea ice. For people living in the Arctic and Subarctic, the presence of the ice can appear as a friend, facilitating, for example, hunting or transport, or as an enemy, disrupting fisheries and navigation (see e.g. Meldgaard 1995, Ogilvie and Jónsdóttir 2000, Ogilvie 2008). For certain marine mammals, the ice is a vital component of their life cycle and habitat. With

the current rapidly diminishing Arctic sea-ice cover, a number of studies are underway to consider the impacts of this major change on Arctic peoples and animals in the present and future (see e.g. Gearheard et al. 2006, http://synice.colorado.edu/, Huntington and Moore 2008 and papers therein). With a view to placing such developments in the context of changes in the past, the focus of this paper is an interdisciplinary study of the interaction of different seal species in Arctic/North Atlantic regions with sea ice, and, more specifically, the implications for the Norse settlements in Greenland in medieval times. Although it is not until the 1970s, with the development of satellite imagery, that truly accurate sea-ice monitoring becomes possible, the existence of a number of data sets documenting past sea-ice variations in the North Atlantic region make it feasible to consider past impacts on both humans and seals.

One hypothesis that will be considered here is that variations in climate played a part in changes and shifts in the seal-hunting patterns of the Norse Greenlanders. Certainly, a transition from less to more ice would be a major threshold shift with serious implications for both marine biology and human society. The reasons for the presence of more or less ice must also taken be into account. Studies of the incidence of sea ice reaching the coasts of Iceland have established a close correlation with temperatures on land (Bergthórsson 1969, Ogilvie 1984 *et seq*.), but the reasons for the presence of sea ice are complex. A large quantity of ice in a certain location could mean colder sea temperatures, and hence a colder climate, or it could also indicate calving icebergs from glaciers during a warmer climatic phase.

Data Sources: Interdisciplinary Evidence

Although the major focus of this paper draws on archaeological data concerning Norse Greenland, it is possible to use evidence, both archaeological and documentary, from Iceland, in order to cast light on conditions in Greenland. The history of the two countries became intertwined when settlers left Iceland around ca. AD 985 (Benediktsson 1968) to form two colonies. One, the larger, was known as the "Eastern Settlement", and was located in the area now occupied by the new municipality of Kujalleq (comprising the former municipalities of Nanortalik, Narsaq and Qaqortoq) in the far southwest. (Qaqortog was previously known as Julianehåb.) The other, much smaller "Western Settlement", was located close to the area of what is now Greenland's capital, Nuuk (formerly Godthåb) a little further to the north on the west coast. For a location map see Fig. 1.While it is difficult to estimate the exact population of the Greenland Norse, it has been suggested that, at the height of the settlements, there may have been around 4000 to 5000 inhabitants in the Eastern Settlement, and 1000 to 1500 in the Western Settlement (McGovern 1981). However, more recent calculations suggest a smaller peak population of about 1000 to 1200 in the Eastern Settlement, and 500 to 800 in the Western Settlement, with a cumulative population over the whole settlement period of around 25,000 individuals (Lynnerup 1996.)

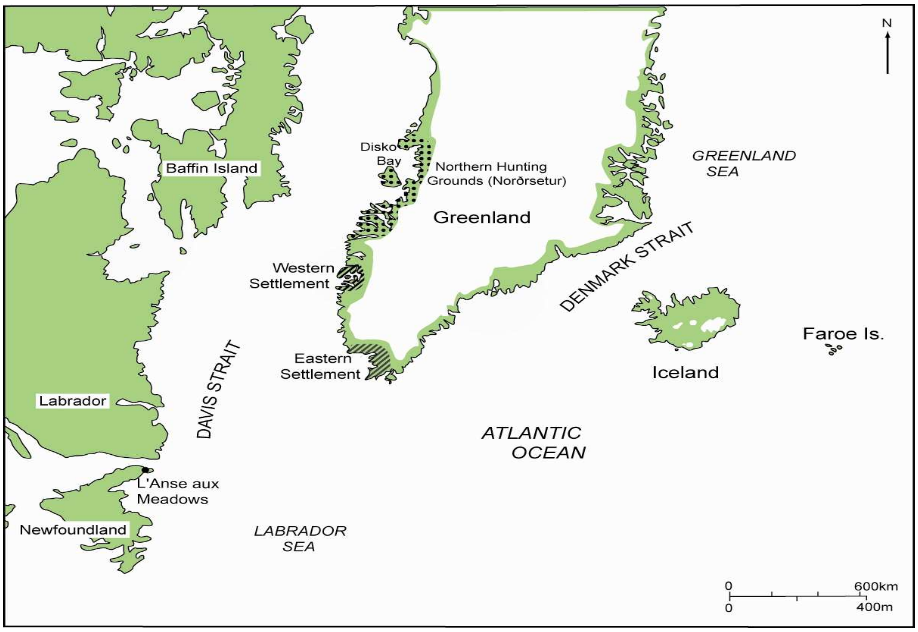

Figure 1. This map of the North Atlantic regions shows the location of the Norse Eastern and Western Settlements as well as the Northern Hunting Grounds (*Norðursetur*) around the Disko Bay area. Map drawn by Kerry-Anne Mairs.

A rich archaeological record is available for both Greenland and Iceland; however, the historical documentary evidence for Norse Greenland is relatively sparse (Halldórsson 1978, Ogilvie 1998) and most of what exists was written in Iceland or Norway. Nevertheless, this latter evidence may help to cast light on conditions in Greenland in the past. Of particular interest is the historical evidence concerning sea-ice variations off the coasts of Iceland (Bergthórsson 1969, Ogilvie 1991, 2005, Ogilvie and Jónsson 2001). See Fig. 2 and discussion below. Proxy climate records (see e.g. Jennings and Weiner 1996, Dietrich et al. 2004, 2005, Jensen et al. 2004, Roncaglia and Kuijpers 2004, Kristjánsdóttir 2005, Moros et al. 2006, Andrews et al. 2009) also give valuable information regarding past variations in climatic conditions and sea-ice cover. Although lack of space precludes any detailed methodological discussion regarding the use of the data presented here, it may be noted that all climate proxy data sets, whether from natural archives, or in the form of written documentary records must be analyzed in the manner appropriate to them. For further information see, e.g. Bell and Ogilvie 1978, Ogilvie 1984, 1991, 1997, regarding documentary evidence, and the references cited above regarding proxy climate data from natural archives. It should also be noted that any use of seal bones from excavated archaeofauna (animal bone collections from archaeological sites) must recognize the filtering effects of past human economic organization, technology, and seal-hunting strategies (see e.g. Woollett 2007).

Sea Ice

Ice on the sea, "sea ice", essentially has two possible origins: i) it is frozen seawater which forms directly on the surface of the ocean; and ii) icebergs which have broken off from calving glaciers. It is one of the most important and variable components of the

planetary surface and is thus the key to understanding many basic questions concerning the energy balance of the Earth. The ice-covered seas represent the cold end of the vast heat engine that enables the Earth to have temperatures suitable for human life over most of its surface. Sea ice also helps drive the oceanic thermohaline circulation through salt rejected by ice formation in critical regions, and directly affects climate through its high albedo, which causes sea-ice retreat to have a positive effect on global warming (see e.g. Wadhams 2000). The causes of the drift of sea ice is not simply a question of colder climate; it is, among other things, a complex amalgam of variations in ocean currents, and surface winds. The most interesting feature of Arctic sea ice at present is the rate at which it is melting, and the projection by models that there is likely to be an even more rapid reduction in the extent and seasonal duration of sea ice in the future (Stroeve et al. 2007, 2008). The implications of these changes are a major cause for concern, for both humans and marine fauna and flora.

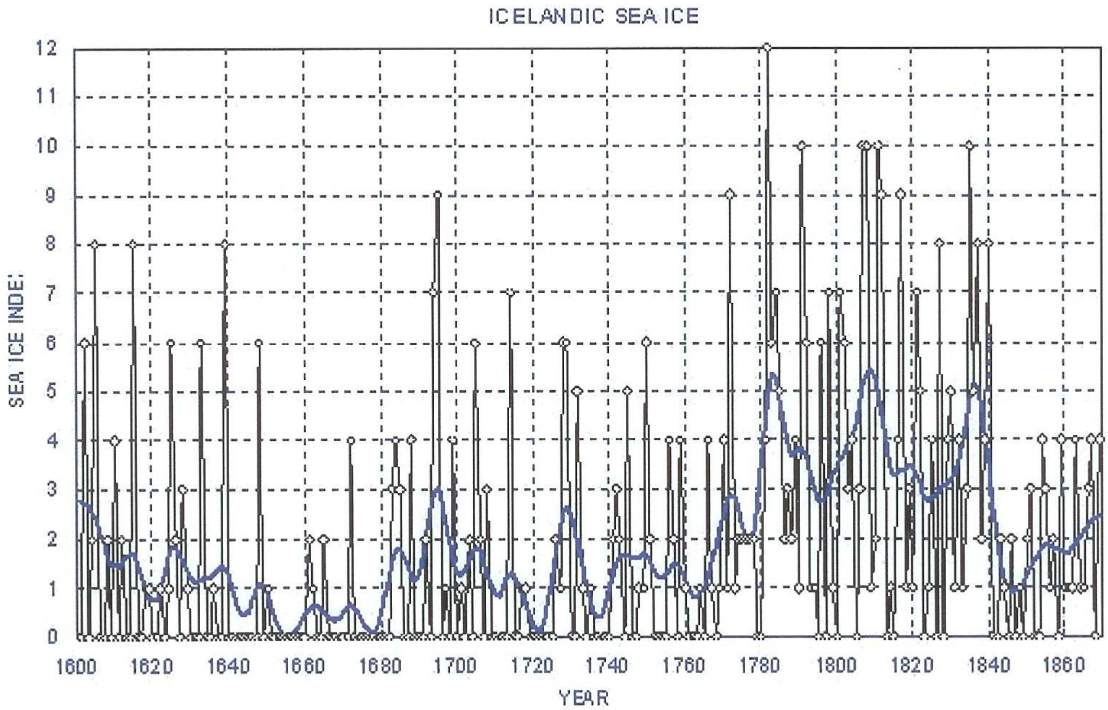

Figure 2. Although the diagram above shows the incidence of sea ice off the coasts of Iceland during a later period than that under consideration here, it illustrates the great variability of the ice from year-to-year and decade to decade. See Ogilvie 1992, 2005.

The sea-ice record from Iceland based on historical data (Fig. 2) does not become continuous until AD 1600 but fascinating descriptions of sea ice in the North Atlantic also exist for earlier periods (Ogilvie 1991, 1992). Some of these may be mentioned here. The earliest detailed account of sea ice is found in the *Konungs Skuggsjá* or “The Kings’ Mirror” (Larsen trans. 1917, Jónsson ed. 1920) an instructional handbook on behavior for all classes of society, but especially kings, composed in Norway most probably around AD 1250 (Holtsmark 1956-78, Ogilvie 1991, 2005). This remarkable work also gives illuminating information on a variety of subjects encompassing human societies and also

the natural world. The description is clear and detailed, unlike many other medieval writings. The unknown author clearly had first-hand information from someone familiar with Norse Greenland and the surrounding seas. The account of known seal species is of particular interest (see below). Some 100 years later, in ca. 1350, a geographical description given in the Icelandic *Guðmundur saga biskups Arasonar* ("The Saga of Bishop Guðmundur Arason") by Abbot Arngrímur Brandsson contains a description of Iceland which notes the presence of much sea ice off the coasts. Although historical sources need to be subjected to careful analysis, this account of the ice is judged to be reliable, as are the accounts referring to sea ice and seal species in "The King's Mirror" (Ogilvie 1991, 1997). The same may not be said of a more problematic account, possibly originating from ca. 1360. This is termed in modern Icelandic *Grænlandslýing Ívar Bárðarsonar**, or, translated into English, "The Description of Greenland according to Ívar Bárðarson", (Jonsson 1930, Halldórsson 1978). It was first written in the language of "middle Norwegian" and the original form of its title is likely to have been *Iffver Bardsen Grönlænder* (*pers.comm*. Christian Keller). This work poses interpretative difficulties primarily because the original text is no longer extant. Furthermore, the transmission of the existing version is complex. It is likely that it is a compilation of several manuscripts which were probably first collected and copied in Bergen in the early 1500s (pers. comm. Christian Keller. See also Ogilvie 1991, 1997, Ogilvie and Jónsson 2001). Included in its brief account are sailing directions from Iceland to Greenland, and the information that the old route has become difficult due to the presence of sea ice. Although it is possible that the greater part of the work may be reliable, the mention of sea ice is almost certainly not part of the original account, but a later interpolation. The interesting description is tantalizing because is not known precisely when the insert on sea ice was written or, indeed, if it is accurate (Ogilvie 1991, Ogilvie and Jónsson 2001).

Figure 3. An iceberg in Eiríksfjord, near Brattahlið. Photograph A.E.J. Ogilvie, 2008.

Two remarkable examples of reliable early geographical treatises were written in Iceland in the late 1500s. These are the *Brevis Commentarius de Islandia* ("A Brief Commentary on Iceland") by Arngrímur Jónsson (1568-1648) who was nicknamed "the learned" (published by Benediktsson in 1950, and in Hakluyt's voyages in 1928). This work was compiled in an attempt to refute erroneous accounts of Iceland which suggested that hell itself was to be found in Mount Hekla or on the sea ice (see Ogilvie 2005). The *Qualiscunque descriptio Islandiæ* ("A Draft Description of Iceland") was first published

in an Icelandic translation in 1971. In the introduction to his edition of this latter work, Benediktsson argues convincingly that the author was Oddur Einarsson, Bishop of Skálholt (1559-1630). However, for a different viewpoint, see also Sigmarsson 2002. Written in Latin in the early 1590s, these two works are the earliest Icelandic accounts which give accurate and detailed descriptions of sea ice (see Ogilvie 2005). After around AD 1600 there are numerous sources which describe sea ice (Ogilvie 1984 *et seq*.). Both early and later sources refer to the hunting of seals on sea ice, as well as to the taking of seals and other marine mammals, such as whales, when trapped in ice close to the shore (Ogilvie 2008).

North Atlantic Seal Biogeography and Behaviour

Six species of seals are found in the modern North Atlantic (Ridgway and Harrison 1981, King 1983, Riedman 1990). For their distribution see http://nlbif.eti.uva.nl/bis/marine_mammals.php?selected=bekijken&menuentry=atlas&id=116. The most widespread is the common (also called harbor) seal, *Phoca vitulina*, which is found in both Atlantic and Pacific waters (Bigg 1981). These terms, "common", and "harbor", seal are used interchangeably here. In eastern and western Atlantic waters, the common seal is found in two sub-specific groups (eastern: *P. v. vitulina,* western: *P. v. concolor)* with a range extending from warm temperate waters into Arctic regions, for example Baffin Bay. In Arctic/Atlantic regions these seals do not generally haul out on the ice. Pupping takes place later in the year than for harp, ringed, and bearded seals, in areas with open water. The seals form small concentrations at favored hauling-out spots on sandy beaches, sandbars, and skerries, where pups are born and raised in early spring. These regularly-used pupping and hauling-out points make this species vulnerable to on-shore human hunters, and common seal populations are particularly subject to local extinction or dispersal by over-hunting. While adult common seals are at home in ice-filled waters, their pups are much more vulnerable, and common seal populations do not thrive in areas with substantial summer drift ice (see Woollett 1997, Woollett et al. 2000).

The grey seal *Halichoerus grypus* is far less common, and is a much larger and more aggressive seal, found in three distinct populations in Canada, the Eastern North Atlantic (Iceland, Faroes, British Isles, Norway, North Sea coasts) and the Baltic. While capable of breeding on ice floes, the grey seal is mainly north temperate in distribution, and is not regularly found in Greenland. Grey seals also form annual breeding and pupping concentrations, generally in smaller groups on offshore rocks less accessible from land than the common seal haul-outs, and are thus somewhat less immediately vulnerable to human predation. Highly visible in coastal areas, common and grey seals have been taken by human hunters in the eastern North Atlantic since the Mesolithic, and are still regularly killed by fishermen seeking to limit competition. Neither common seals nor grey seals are migratory, and thus local groups of both species are subject to overexploitation or extirpation.

Ringed seals, *Pusa hispida*, are true arctic seals, capable of making and maintaining breathing holes in fast ice. They have an early breeding season, pup on fast ice, and regularly maintain ice dens in which pups are born. Ringed seals have a wide circumpolar

distribution, and are also found in the northern Baltic, with related species occurring in the Caspian Sea and Lake Baikal. This seal is non-migratory and does not form substantial seasonal concentrations, but is common within its distribution area, forming a major food source for both polar bears and human hunters across both low and high arctic regions. It has been hunted since prehistoric times (Murray 2005).

Bearded seals, *Erignathus barbatus*, are very large seals with a circumpolar distribution, also capable of maintaining breathing holes and surviving in high arctic conditions. Like the ringed seals, they are not migratory, and neither species is regularly encountered in southern Norway, the British Isles, the Faroes, or Iceland. Complex, species-diverse patches of populations exist in areas with heterogeneous environments in close contact with outside "core" populations which are sources for recruitment to other populations. While there is some overlap between the ranges of the north temperate non-migratory seals (common and grey seals) and the arctic non-migratory seals (ringed and bearded seals), year-round ice conditions strongly favor the arctic-adapted species in range-margin competition (as in Labrador; Woollett 1999 2003, Woollett et al. 2000).

In addition to these pairs of non-migratory north temperate and arctic seals, the North Atlantic is also home to two species of ice-riding migratory seals. The harp seal, *Phoca groenlandica*, has three distinct populations: one northwest Atlantic population breeding on the early spring ice in the Gulf of St. Lawrence, and off Newfoundland and southern Labrador, and then migrating up the coast of Greenland; another East Greenland sea population breeding near Jan Mayen Island in the northeast Atlantic; and a third population breeding in the Barents Sea/White Sea area. In spite of human predation, harp seals are probably the most numerous seals on earth, with current population estimates for the northwest Atlantic group ranging between 4 – 6 million. Individual seals are occasionally encountered as far south as New York harbor, but most harp seals are normally closely associated with movements of drift ice in the North Atlantic. The migratory pattern of the northwest Atlantic population brings them to the southwest coast of Greenland regularly each spring in immense numbers, and they travel northwards along the west coast to north of Disko Bay before returning to the Canadian coast. The northwest Atlantic harp seal population thus represents a major resource for human hunters on both sides of Davis Strait.

The other migratory ice-riding seal species is the hooded or bladder-nosed seal, *Cystophora cristata*, a larger animal with a smaller population size (northwest Atlantic modern population estimated at around 400,000). Four distinct hooded seal populations (their range often overlapping with harp seals) can be found on the pack ice near Jan Mayen Island, off Labrador and northeastern Newfoundland, in the Gulf of St. Lawrence, and in Davis Strait southwest of Greenland. These large migratory seals follow a somewhat different path from the harp seals, congregating with the harps off the fjords of southwest Greenland in the spring, but then mainly moving up the east coast of Greenland in summer. Inhabiting pack-ice masses far offshore, they are not accessible to human hunters in much of west Greenland, apart from the extreme southwest.

The six species of North Atlantic seals may thus be said to form three pairs: a north temperate group (common and grey seals); a high arctic group (ringed and bearded seals); and an ice-riding migratory group (harp and hooded seals). In each case, the smaller of the pair is the more numerous, and harp seals probably greatly outnumber all other species combined. These three pairs of species do have partially overlapping ranges, but have very different associations with summer and winter drift and fast ice. Their behavior also produces quite different vulnerabilities to human hunting. The common and grey seal populations most familiar to Celtic and Nordic hunters prior to the trans-Atlantic expansion of the Viking age form predictable seasonal concentrations at recurring locations – excellent hunting targets but subject to depletion and local extinction. The dispersed but abundant arctic ringed and bearded seals have long provided a key resource for North American arctic hunters, but require specialized harpoon technology and ice-hunting skills for their regular capture. The migratory seals (especially harp seals) provide a virtually inexhaustible abundance for a relatively short period of time over most of their range, requiring a highly focused but potentially very productive hunting effort. The differing biological requirements of these six seal species thus provide a potential set of proxies for past climate, especially sea-ice conditions.

Norse Seal Hunting in the North Atlantic

Seal hunting in the Baltic and North Atlantic extended into the Mesolithic era, and, through the centuries, different cultures have made use of a wide variety of hunting techniques (Härkönen et al. 2005, Storå 2002, Armit 1996, Clark 1946). The Viking-age settlers of the North Atlantic islands thus had a long heritage of sealing, but by the ninth century AD, seal hunting had become a very limited portion of a subsistence economy centered on fishing, barley growing, and herding of domestic mammals in most of western Scandinavia and the British Isles. Archaeofauna from both Pictish and Norse contexts in Shetland, Orkney, Caithness, and the Hebrides, usually produce some common and grey seal bones, but these comprise far less than 10% of each collection (Perdikaris and McGovern 2008). Similar patterns are reflected in Viking-medieval archaeofauna from Sandoy in the Faroe Islands (Church et al. 2005) and in most Viking age Icelandic sites (McGovern et al. 2001). In the eastern North Atlantic during the Viking Age and early medieval period seals (almost exclusively common and grey seals) thus tended to represent a locally useful supplement to subsistence, an occasional source of good quality fat and skins, and a product that could sometimes find its way far inland, but not a critical staple for either regular subsistence or large-scale external trade. The situation was somewhat different in Greenland, however. For a comparison of the frequency of seal bones versus mammal bones found in a sampling of sites across the North Atlantic see Fig 4.

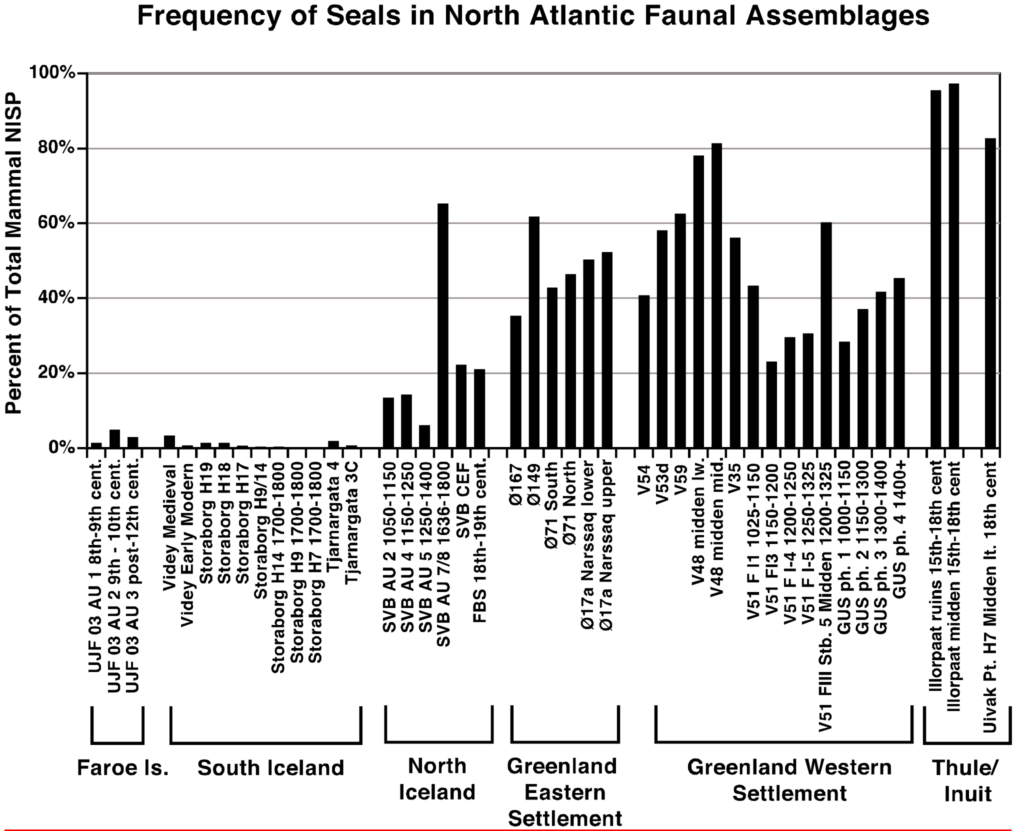

Figure 4. This graph shows the frequency of seal bones (all species) as a percentage of all mammal bone (%NISP) in a sampling of sites across the North Atlantic. Seals present uniformly minor parts (<5%) of mammals from farm sites in the Faroes and coastal southern Iceland, independent of period. Seals are much more commonly observed in some coastal northern Icelandic sites, with seals comprising the majority of mammals in the early modern assemblage of Svalbarð. In Greenland, seals comprise more than 30% of mammal bones in almost all farm sites shown here, with several sites having seals as the majority of the mammal assemblage. V48, in particular, shows a proportion of seals which parallels that of Thule and Inuit winter sites in West Greenland and Labrador, where subsistence economies were built almost entirely around seal hunting.

Seal Hunting in Iceland

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 extremely important addition to the daily diet, especially at times when other traditional food sources failed. Several proverbs testify to this fact, including *Selurinn er sæla í búi* “A seal means contentment in the home”. The main seals that were hunted were *landselur* (common seal), *útselur* (grey seal) and also *vöðuselur* (the harp seal). Luðvík Kristjánsson states that the *blöðruselur* (hooded seal), *kampselur* (bearded seal), and *hringanóri* (ringed seal), in particular the latter, were also taken. Kristjánsson describes the ways in which the seals were hunted, including the varied uses of netting and clubbing. Seal hunting appears to have been practised all around the coasts of Iceland, although he notes that harp seals were only caught on the north and west coasts, and that the usual method was harpooning, although netting was also used in the

eighteenth and nineteenth centuries. Kristjánsson also describes a variety of additional methods used in seal hunting, including the digging of pits, and the placing of iron spikes on rocks where the seals would be caught fast. The use of harpoons ceased in 1875.

In the seventeenth century, there were 364 coastal farms that had sealing rights. However, according to the land registers of 1702-12 only 215 such farms were recorded. In 1932, the total number of such farms was 264 (Kristjánsson 1980). The reason for the apparent decline in sealing in the early eighteenth century is not clear. Seal-hunting rights were considered highly valuable. The skins do not appear to have been exported until the eighteenth century, but were in great demand within the country, especially for the making of shoes. Sealskin shoes were considered superior to shoes made of leather as they were more durable in wet conditions (Ingi Unnsteinsson, pers.comm.). Seal meat was also an important food source, and was used fresh, salted and smoked.

The hunting of seals is described in many of Iceland's varied historical records, including the *Sagas of Icelanders*. In *Egil's Saga*, for example, it is said of Skallagrim, an early settler, that "He had a farmstead built on Alftanes and ran another farm there, and rowed out from it to catch fish and cull seals..." (*The Complete Sagas of Icelanders*, I:66). An example of a description of seal hunting on sea ice may be taken from the *Brevis Commentarius de Islandia* written in 1592 by Arngrímur Jónsson (noted above). Clearly, seal hunting was an "ancient custom". Because harp seals are associated with sea ice, and were one of the most frequent seals taken, it is likely that the seals in Arngrímur's description below refer to this species.

> *Why; it is an ancient custome of the Island that they which inhabite neare the sea shoare do usually go betimes in a morning to catch Seales, even upon the very same ise which the historiographers make to be hell, and in the evening returne home safe and sound.* (From Arngrímur Jónsson's *Brevis Commentarius de Islandia* translated in *Hakluyts Voyages* 1904 vol. IV:123.)

Although the presence of sea ice off the coasts of Iceland had primarily negative effects such as: the lowering of temperatures on land which, in turn, could adversely affect the all-important grass crop; the prevention of fishing; and the hindrance of trading vessels from landing, the marine mammals that were often brought with the ice were an important addition to the food supply (Ogilvie and Jónsdóttir 2000). Arngrímur Jónsson also notes that harp seal and ringed-seal pups were sometimes carried inshore by drift ice and were then clubbed, often in great numbers. With the general decline of sea ice off the coasts of Iceland from the early-twentieth century onwards, the harp and ringed seal have been less in evidence recently than in former times (Kristjánsson 1980, Sergeant 1991).

The documentary evidence regarding seal hunting in Iceland is corroborated by the archaeological record. Here it may be noted that there is regional variability in seal-bone abundance, with archaeofauna from the West Fjords district in the northwest, Þistilfjörður in the northeast, and the island of Flatey in Breiðafjörður showing the greatest abundance of seal bones (Amorosi 1992, Amundsen 2003, Edvardsson and McGovern 2005). A few seal bones have also been recovered from inland Icelandic sites dating to both the ninth

and tenth centuries, and to early modern contexts, suggesting at least a local pattern of movement of seal products from coast to inland consumers (Amorosi 1996, McGovern et al. 2006). The regular recovery of newborn (neonatal) common seal bones in all these Icelandic sites indicates a spring hunt focused upon pupping beaches, probably supplemented by net hunting of adults in other seasons. Kristjánsson (1980) notes that as the common seal has its pups in the spring or early summer, and the grey seal in the autumn or early winter, the two species were also referred to as spring and autumn seals, respectively.

The pattern of recovery of seal products is reflected in, for example, the post-medieval layers of the deeply stratified farm midden at the site of Svalbarð in Þistilfjörður in northeastern Iceland (Amorosi 1992). In this archaeofauna, harp seal bones are present in substantial numbers by the seventeenth century, eventually outnumbering cattle bones. This pattern seems to reflect the sort of locally intensive hunting activities on the sea ice described in the passage from Arngrímur Jónsson cited above. Other finds of harp seal bones in fourteenth-century contexts at Gásir in Eyjafjörður (Harrison 2007, Harrison et al. 2008a), from early modern contexts at Vatnsfjord (Pálsdóttir et al. 2008) from Eyri in the West Fjords (Taylor et al. 2005, Harrison et al. 2008b) and from Hofstaðir in Mývatnssveit (McGovern et al. 2007) may also reflect periodic use of harp seals. However, at present, only the Svalbarð archaeofauna indicates intensive harp-seal hunting, thus reflecting a major dietary supplement to farming and fishing.

Figure 5. Statue of Sæmundur and the seal in front of the University of Iceland, Reykjavik. Sculpture by Ásmundur Sveinsson. Photograph A.E.J. Ogilvie, 2008.

It may be noted that seals also feature greatly in Icelandic folklore, perhaps a reflection of their importance for subsistence. A well-known example concerns the scholar, historian, and priest, Sæmundur fróði, or Sæmundur the Learned, who lived from 1056-1133. According to the folk tales collected by Jón Árnason (1956) it is said of Sæmundur that he tricked the devil into assuming the shape of a seal so that he could swim with him to Iceland on his back. The context of the story is that Sæmundur covets a desirable property in the south of Iceland, named Oddi, but so do others. The King of Norway decides that the man who gets there first, from Norway, shall have it. The story goes that Sæmundur tells the devil that if he can be brought ashore without him getting his cloak wet, the devil may have his soul. When they are close to shore, Sæmundur hits the seal on

the head with a psalter, causing him to sink, and then swims to shore by himself. He gets Oddi. A statue, completed in 1926 by the Icelandic sculptor Ásmundur Sveinsson, which shows Sæmundur smiting the devil/seal is to be found in front of the main building of the University of Iceland in Reykjavik (see Fig.5).

Seal Hunting in Norse Greenland

When Norse settlers arrived in West Greenland in the late-tenth century, the Viking Age Icelandic pattern of small-scale low-intensity seal predation was changed dramatically in this new location. The zooarchaeological record indicates that the Norse Greenlanders immediately recognized the tremendous potential of the newly-encountered migratory harp and hooded seal populations, as the earliest archaeological contexts dating to the late-ninth century produce great quantities of seal bone from these species. Stratified archaeofauna tend to show a steady increase in seal bones through time, with seal-bone relative percentages ranging from 30 to over 80% of the total archaeofauna, on both coastal and far inland farms (McGovern 1985a, 1985b, Perdikaris and McGovern 2008). Clearly, seals were a critical subsistence staple in Greenland, and the thirteenth-century source noted above, *The King's Mirror*, lists seal skins and fat among Greenlandic trade exports. This work also contains a fascinating description of known seal species, given below:

> *In those waters there are also many of those species of whales which we have already described. It is claimed that there are all sorts of seals, too, in those seas, and that they have a habit of following the ice, as if abundant food would never be wanting there. These are the species of seals that are found there. Once is called the "corse" seal; its length is never more than four ells. There is another sort called the "erken" seal, which grows to a length of five ells or six at the very longest. Then there is a third kind which is called the "flett" seal, which grows to about the same length as those mentioned above. There is still a fourth kind, called the bearded seal, which occasionally grows to a length of six ells or even seven. In addition there are various smaller species, one of which is called the saddleback; it has this name because it does not swim on the belly like other seals but on the back or side; its length is never more than four ells. There remains the smallest kind, which is called the "short seal" and is not more than two ells in length. It has a peculiar nature; for it is reported that these seals can pass under flat ice masses four or even five ells thick and can blow up through them; consequently they can have large openings wherever they want them*. (Larsen trans. 1917, *The King's Mirror-Speculum Regale-Konungs Skuggsjá*:139-140.)

It may be noted that an "ell" is approximately 56-58cm. The last seal mentioned, the "short" seal, sounds very much like the ringed seal. According to the notes in Larsen's translation of *The King's Mirror*, the "saddleback" corresponds to the harp seal. The same source suggests that the "erken-seal" is the same as the grey seal. The "bearded" seal is clearly *Erignathus barbatus*. It may be conjectured that the "corse" seal is the common seal, and the "flett" seal is the hooded seal.

The biogeography of seal-migration patterns seems to have affected the Norse seal catch, since hooded seals were commonly taken in the Eastern Settlement in the far southwest but are rare in Western Settlement archaeofauna (see Fig. 6 showing later phases of mean seal catches). Sealing technology and hunting techniques as well as seal biogeography also affected the seal species taken regularly by Norse hunters. Medieval to Early Modern Scandinavian sealing techniques seem to have included the use of seal nets, and fragments of nets made from whale baleen have been recovered from *Gården under Sandet* (GUS) "The Farm Beneath the Sand" in the Western Settlement (Arneborg pers.com.). Interestingly, a recent study of ancient "dirt" DNA from this farm also corroborates the pattern seen elsewhere of a general increase in the ratio of seal bones to other domestic mammals over time (Hebsgaard et al., 2009). Clubbing on land and on sea ice certainly occurred, and possibly also the use of boat drives into net barriers (McGovern 1985a, 1985b, Kristjánsson 1980:317-405; Fenton 1978). The use of harpoons or barbed spears so characteristic of Inuit seal hunting technology do not appear to have been used. However, seal harpoons are mentioned in thirteenth-century sources in Iceland, and were used in western and northern Iceland where harp and hooded seals were available (Orri Vésteinsson, pers.comm.).

Figure 6 Mean of identified seal species from Eastern and Western Settlement archaeofauna dating to later phases (older collections are probably all post-1250, only the latest phases of stratified collections included).

The Greenland Norse apparently did not make significant use of harpoons or ice-hunting techniques, but concentrated instead upon mass netting and clubbing of seals on land, or on drift ice, by coordinated groups of hunters. While much remains to be learned about Norse sealing in Greenland, the presence of large amounts of seal bone in inland farms may suggest the special communal nature of Norse sealing (McGovern 1985a, 1985b, McGovern et al. 2006; Smiarowski et al. 2007, Dugmore et al. 2008). Analysis of available seal dental annuli suggests a hunt concentrated in spring/summer (McGovern et al. 1996). The Norse sealing methods in Greenland seem to have been directly adapted from methods used to hunt common seal colonies in the eastern North Atlantic, and stressed communal collaboration and coordinated attacks on groups of seals rather than individual hunters stalking and killing individual animals. These strategies were well suited to taking many of the seasonally-concentrated migratory harp and hooded seals, as well as taking large quantities of the familiar common seals, and probably worked quite effectively to provision the settlements (Dugmore et al. 2007). However, the communal sealing strategies employed by the Norse were not as effective in taking substantial numbers of ringed or bearded seals, which nineteenth- to twentieth-century catch statistics, as well as scattered paleoeskimo archaeofauna, suggest were present in both Norse settlement areas in substantial numbers (see discussion in McGovern et al. 1992a, 1992b). Any climatic cooling that would promote additional fast-ice formation in winter or longer periods of stable ice in spring would tend to favor these species, so the shortage of ringed and bearded seal bones in the later Norse archaeofauna probably reflects hunting technology rather than species abundance. In short, it is likely that the high

Arctic seal species were present in large numbers in Viking times. Certainly the complex indented shoreline and exposure to pack ice should have created mosaic ice environments on a generalized scale within the region (McGovern, 1985a, 1985b, Gotfredsen and Moberg 2004).

Comprehensive Greenlandic seal-catch records (Fig. 7) provide a useful picture of recent hunting patterns by modern Greenlanders in the two former Norse settlement areas (Vibe 1967, McGovern 1991). These recent sealing patterns contrast with the patterns in the Norse archaeofauna in the far larger number of ringed seals taken by modern Greenlanders, but provide a consistent biogeographical pattern in the absence of hooded seals from the Nuuk/Western Settlement area. Today, Qaqortoq and Narsaq districts are heavily affected by summer drift ice carried around Cape Farewell from East Greenland and Denmark Strait, and as a result, common seals are very rarely seen or hunted in these districts. Further north, common seals are regularly taken in the inner fjords of Nuuk district (around modern Kapisillit) which are not affected by summer drift ice.

Figure 7. Modern catch records for Qaqortoq and Narsaq districts (covering the former Norse Eastern Settlement) and the village of Kapisillit (a small settlement in Nuuk Fjord) in the middle of the former Western Settlement.

Archaeological Evidence: What the Bones Tell Us

Archaeological evidence highlighted here includes changes in the relative proportion of seal bones from sites in the Eastern Settlement area (see Fig. 8) as well as stratified seal-bone collections from both the Eastern and Western Settlement areas (see Fig. 9). Data are also available on the ratio of seal bones to the main domestic mammals (cattle, sheep, and goats) from the major chieftain's farm at Brattahlið (E29a) in the Eastern Settlement, and what is probably the second-ranking chieftain's farm at Sandnes (W51) in the Western Settlement (see Fig. 10). The discussion below considers whether the changes shown are due to changes in culture, technology, or climate. Another approach to the same question may be to compare the changing ratio of bones of the major domesticates for the two same sites (Fig. 11).

Fig. 8 presents the identified seal bones recovered from the quantifiable Phases III-V from the 2005-06 excavations at Brattahlið (Edvardsson and McGovern 2005). Harbor seal bones are far more prolific in the lower layers than the modern catch data would

predict, and early-thirteenth century Norse hunters seem to have taken these seals in some numbers. Harbor seals appear to have then declined sharply in abundance between the early- and late-thirteenth century in the substantial Brattahlið N farm archaeofauna.

Figure 8. Relative proportions of identified seal bones. Phase V n= 41, Phase IV n = 44, Phase III n= 14.

While the scarcity of ringed seal bones in these Norse deposits is almost certainly the product of a very different seal-hunting technology and social organization from that of modern Inuit Greenlanders, the presence of substantial numbers of common seals in earlier phases, and their reduction in later phases, is not readily explained by technological or social differences in the seal hunters. The observed change occurs entirely within the Norse cultural context during a period of apparent cultural stability.

Common seal populations tend to be localized, and it is certainly possible that particular pods could have been wiped out or forced to relocate to less accessible hauling-out locations by over-exploitation. However, it would be expected that such impacts would have occurred earlier in the settlement process. By around AD 1250, the Norse had been hunting in this part of Greenland for about nine human generations. Understanding of Norse natural-resource management capabilities pioneered by archaeologists such as Degerbøl (1934, 1941) has been expanded by recent work in Iceland and the Faroes, where there is growing evidence for successful community-level management of seabirds, waterfowl, freshwater fishing, and common grazing (Church et al. 2005, McGovern et al. 2006, Simpson et al. 2002, 2003, 2004). As more has been learned regarding Viking-Medieval Norse economy in the North Atlantic, previous theories of widespread heedless depletion of all forms of natural capital (e.g. McGovern et al. 1988) are being replaced by evidence of more sophisticated and successful resource management (Dugmore et al. 2008). Common seal populations are still sustainably hunted in several parts of Iceland today on a small scale. However, Icelandic sealing has clearly been very different in scope from the far larger Greenlandic effort, and unanticipated consequences or unavoidable circumstances can certainly overtake management strategies on the local scale. A broadening of the data set to include more sites in both settlement areas may be helpful in assessing the two hypotheses (see Fig. 9).

Fig. 9 compares available stratified seal-bone collections in both settlement areas. These collections may be roughly sorted temporally, by radiocarbon and stratigraphy to *before* versus *after* the late thirteenth/early fourteenth century. In the Eastern Settlement area, both the older archaeofauna from E17a at Narsaq, and the 2005-06 Brattahlið North Farm (E29a) phased collections show similar patterns of abundant common seal bones in the earlier layers, and a sharp reduction in the later layers. The two sites are far enough apart that it is unlikely that both would have hunted the same local common seal pods, suggesting a wide impact rather than a local depletion. In the Western Settlement, collections from *Gården under Sandet* (GUS), W51 Sandnes, and the small site W48 all continue to contain varied, but always substantial, amounts of common seal bones both before and after the late-thirteenth century (Enghoff 2003, McGovern et al. 1996). The W51 Sandnes site is close to what was the largest common seal hauling-out and pupping ground in this portion of Nuuk district in the early twentieth century, and the continued

availability of common seals throughout the Norse occupation at Sandnes may be another argument in favor of successful management of common seal resources.

Figure 9. Identified seal species from stratified sites in both the Eastern and Western Settlements. Broad vertical lines roughly divide archaeofauna from before and after the later thirteenth century in both settlement areas. Data: Enghoff (2003); McGovern *et al*. (1993); McGovern *et al*. (1996).

Zooarchaeological evidence for such sea-ice impacts upon farming systems is inevitably indirect, and is complicated by local social and economic factors. However, a comparison of two comparably-excavated midden deposits from higher-status farms spanning the thirteenth century sea-ice transition may suggest some directions for further investigation.

Figure 10. A direct ratio of seal bones to the bones of the major Norse domestic mammals (cattle, sheep, goats). Taller bar indicates more seal bones.

Fig. 10 compares the ratio of seal bones to the major domestic mammals (cattle, sheep, and goats) from the major chieftain’s farm at Brattahlið (E29a) in the Eastern Settlement and from what is likely to have been the second-ranking chieftain’s farm at Sandnes (W51) in the Western Settlement (McGovern et al. 1996, Smiarowski et al. 2007). While there is some controversy regarding the secure identification of the archaeological site E29a with the top-ranking chieftain’s farm at Brattahlíð as mentioned in the written sources (Guldager, 2002), E29 was clearly a major manor with buildings as large as Sandnes. The E29 hall floor area was approximately 66 sq meters, and the cattle byre was 127 sq meters. The hall of Sandnes W51 was approximately 72 sq meters and the cattle byre was 84 sq meters (data from McGovern 1992). Like all other stratified archaeofauna known thus far, both site collections show an increase of seal bones relative to domestic mammals with time, but there would appear to be some marked differences in the rate and amount of increase in seal bones relative to domestic mammals at the two sites. The Western Settlement chieftain’s farm shows a ratio ranging from just over 1:1 to just under 1:2 , while the Eastern Settlement collection shows a shift from around 2.5 seal bones per domesticate bone to just over 4:1 between the early thirteenth and the fourteenth century. If models which see seals as a secondary resource used to fill provisioning gaps left by the farming economy and the caribou hunt are correct (McGovern 1985a, 1985b, Perdikaris and McGovern 2007), these ratios may suggest diverging solutions to the ongoing problem of provisioning large high status households. Were the managers of the Eastern Settlement manor facing drift-ice problems not shared by their contemporaries further north?

Another approach to the same question may be to compare the changing ratio of bones of the major domesticates for the same two sites (see Fig. 11).

Figure 11. The ratio of cattle bones to both sheep and goat (caprines) bones at Brattahlið in the Eastern Settlement and Sandnes in the Western Settlement.

The proportion of high-status cattle bones to lower-status caprines (sheep and goats together) has often been used as a site status indicator in North Atlantic zooarchaeology.

There certainly tends to be a close association between larger farms with richer pastures and a higher proportion of cattle bones in the site middens (McGovern 1985a, 1985b, 1992a, 1992b, Enghoff 2003). As Fig. 11 indicates, both Sandnes W51 and Brattahlið E29 maintained a virtually identical "high status" Greenlandic profile through the thirteenth century, but after ca. 1300 there appears to have been a significant shift at the Eastern Settlement site towards sheep and goats. These species may have been culturally less prestigious but required about a sixth of the winter fodder consumed by a cow, and could be maintained on lower quality pastures. While further research needs to be done, it appears that the challenges posed to Eastern Settlement residents at all status levels by the sea-ice changes of the thirteenth century may be visible in the archaeological record. *Two hypotheses may be advanced to explain the marked transition in the archaeofauna noted above: either the stocks of common seals have been depleted in the Eastern Settlement area due to over-hunting by Norse sealers, or; the climate changed from warmer conditions with little or no summer drift ice to a climatic regime with more sea ice during the later thirteenth century.* Evidence for changes in sea-ice regimes is considered below.

Proxy Climate Data: What the Natural and Human Archives Tell Us

North Atlantic palaeoclimate data and documentary data (the latter mainly from Iceland) help to cast light on past sea-ice conditions. The very earliest mention of sea ice in the Icelandic annals is for the year AD 1145, but as this is an isolated account, it is difficult to evaluate (Ogilvie, 1991). There is some further evidence from Iceland that the latter part of the twelfth century experienced a relatively harsh climate. These kinds of records also suggest relatively cold conditions in the late 1200s (Ogilvie 1991).

The King's Mirror, noted above, and possibly written around AD 1250, describes sea ice in Denmark Strait, but the account is tantalizing because it is unclear if this is perceived as a new or a persistent threat to navigation:

> *As soon as one has passed over the deepest part of the ocean, he will encounter such masses of ice in the seas, that I know of no equal of it anywhere else in all the earth. Sometimes these ice fields are as flat as if they were frozen on the sea itself...There is more ice to the northeast and north of the land than to the south, southwest, and west; consequently, whoever wishes to make the land should sail around it to the southwest and west, till he has come past all those places where ice may be looked for, and approach the land on that side. It has frequently happened that men have sought to make the land too soon and, as a result, have been caught in the ice floes. Some of those who have been caught have perished; but others have got out again, and we have met some of these and have heard their accounts and tales. But all those who have been caught in these ice drifts have adopted the same plan: they have taken their small boats and have dragged them up on the ice with them, and in this way have sought to reach land; but the ship and everything else of value had to be abandoned and was lost. Some have had to spend four days or five upon the ice before reaching land, and some even longer*. (Larsen trans. 1917, *The King's Mirror-Speculum Regale-Konungs Skuggsjá*:138-139.)

The Icelandic annals and certain sagas suggest that the 1360s and 1370s were cold on the whole, but the time span 1395 to 1430 was probably comparatively mild. However, the paucity of the data makes it very difficult to draw hard and fast conclusions based on them. Information from these annals and sagas, as well as other written records, is described in detail in Ogilvie (1991).

Relevant palaeoclimatic data include evidence from two high-resolution marine sediment cores from Nansen Fjord, off eastern Greenland, which were collected in 1991 (Jennings and Weiner 1996). Analyses of the cores taken show evidence of changes in oceanographic and sea-ice conditions from c. AD 730 to the present. The changes are inferred primarily from two independent lines of proxy evidence for environmental change. These are variations in ice-transported debris and *foraminifera*. Both types of evidence suggest that the interval from AD 730 to 1100 was one of relatively warm and stable conditions, and that there were also two cold intervals that culminated in c. AD 1150 and c. AD 1370 (Jennings and Weiner 1996, Ogilvie et al. 2000). Ice-core records from Greenland suggest a period of relatively low temperatures (when normalized to a 700-year mean) ca. 1343-62 (Barlow 1994, Barlow et al. 1997).

Other examples of palaeoclimatic data are drawn from a location in the Eastern Settlement site, in the Igaliku fjord close to the Norse site of Garðar. Using sediment cores collected in 1998 from both the inner and outer part of the fjord, Jensen et al. (2004) undertook analyses of hydrographic changes and sea-ice conditions over the past 1500 years. Currently, sea ice carried by the East Greenland Current is present in the outer part of this fjord for several months per year. Southeast of the fjord, in the Cape Farewell (Uummannarsuaq) area, the concentration of drift ice has usually been greatest between February and June (Buch 2000). Jensen et al. (2004) focus on the analysis of different species of diatoms (aquatic microorganisms) found in the core material. As different species flourish under different prevailing temperature and sea-ice conditions, it is possible to deduce changes in these parameters by noting the numbers of different types of diatoms in different sections of the cores. The analysis suggests a cold and presumably moist climatic regime prevailing from ca. AD 535 to 770. From then to around AD 1245 hydrographic conditions were characterized by limited sea ice and the influence of Atlantic (warmer) water. This was punctuated by episodes of in-flow of colder water around AD 960 and 1080. Marked hydrographic changes began around AD 1300 and culminated around 1500. Specifically, it would appear that advection of ice-loaded Polar water by the East Greenland Current into the fjord entrance markedly increased after c. AD 1300, while the ice coverage of the inner part of the fjord became more extensive (Jensen et al. 2004). These authors suggest that their results support the hypothesis that one of the reasons for the loss of the Norse settlements was climatic deterioration (Jensen et al. 2004).

A further study of the core taken at the entrance of Igaliku fjord used palynofacies analysis (changes in the abundance of various types of sedimentary organic matter – SOM) with the aim of reconstructing late Holocene palaeo-oceanographic changes in the North Atlantic and in Greenland coastal waters (Roncaglia and Kuijpers, 2004). In

particular, the presence of a variety of dinoflagellate assemblages present in the core were used to assess the palaeohydrographic conditions during deposition of the sediments. Based on this evidence, it is suggested that cold conditions with extensive sea ice prevailed from 3300-1180 BP, i.e. prior to around AD 770. Subsequently, a period of climatic amelioration is suggested to AD 960. The evidence of "sea-ice" diatoms prevailing during ca. AD 1245-1680 noted in Jensen et al. (2004) is paralleled by the cooling trend from AD 1285 noted by Roncaglia and Kuijpers (2004). On the basis of this evidence, more than 6 months of sea-ice cover per year would be expected in the Igaliku fjord area after c. AD 1300 (Roncaglia and Kuijpers, 2004). In a parallel study to that of Jensen et al (2004) and Roncaglia and Kuijpers (2004), Lassen et al. (2004) analysed *foraminifera* fauna from the outer part of Igaliku fjord. They concluded that intensified wind stress and overall environmental changes may have contributed to the loss of the Norse settlement in Greenland. It is interesting to note a comment in the Icelandic Annals for the year 1287: "At this time, many severe winters came at once, and following them people died of hunger" (Ogilvie 1991).

A study of Holocene environmental changes in an area somewhat to the north of the Eastern settlement area, in central west Greenland, was begun in the year 2000 with the aim of understanding their relationship to large-scale North Atlantic atmosphere and ocean circulation changes (Moros et al. 2006). For this study, diatom and lithological analyses were carried out on two sediment cores from the Disko Bugt area and the adjacent Kangersuneq Fjord. The authors found no evidence for a marked warming during the traditionally dated "Medieval Warm Period" in the Disko Bugt core. Indeed, the period of 1.7 to 0.7 kyr BP appeared to include the coldest period overall of the entire investigated period. Clearly, in the Greenland region, as elsewhere, climatic anomalies are characterized by complex patterns (Moros et al. 2006). However, evidence was found for a possible link between hydrographic (sea-ice) changes and human settlement and hunting history. In particular, it is suggested that the period of the Saqqaq settlement (4.4.-3.4 kyr BP) was characterized by relatively high sea-surface temperature (SST) conditions, which was favorable for these people, who were preferentially open-water hunters (Meldgaard 2004). In contrast, the Dorset people (2.8-2.1. kyr BP) were more adapted to sea-ice hunting. The oldest era of this culture is suggested to be coincident with low SST conditions and a more extended sea-ice cover in Disko Bay.

Two marine-based proxy records from northern Iceland (Kristjánsdóttir 2005) and from northwestern Iceland (Dietrich et al. 2004, 2005) show great variability in the sea-ice and climate record, with a general gradual cooling over the past 1000 years to the present (northern Iceland) and a mild period peaking around AD 850 with gradual cooling to around AD 1600 (northwestern Iceland) respectively. For a longer-term perspective on sea-ice variations see Andrews et al. (2009).

Discussion: Potential Impacts of Summer Drift Ice in Greenland

The most immediate impacts of the onset of regular summer drift ice adjacent to the Eastern settlement area would have been on the maritime components of the Norse economy; local and international seafaring and maritime subsistence activities. Norse

sealing parties would clearly have been affected by the disruption of established common seal colonies. By around the mid-thirteenth century, these may well have been formally owned and communally regulated. The "Description of Greenland" according to Ívar Bárðarson, noted above, although problematic as regards its sea-ice description, may well give an accurate picture of conditions in Norse Greenland in the second half of the fourteenth century when it is written that the rights to fishing and hunting grounds were owned by the large land owners (Jonsson 1930, Halldórsson 1978). The multiple problems and hazards imposed on small boat traffic in increasingly ice-filled waters would also have impacted hunting activities. Apart from seasonal sealing expeditions and the long-distance voyaging to the northern hunting grounds around modern Disko Bay (McGovern 1984, Perdikaris and McGovern 2007), much of the daily travels of farmers along the steep-sided fjords within the core settlement areas would have been carried out by boat, and some farms are extremely difficult to reach on foot. As a comparison it may be noted that, in the present day, summer drift ice can completely block access to coastal settlements even by modern steel-hulled ships in the former Eastern Settlement area, cutting off communities for weeks at a time.

It is not certain if the Norse Greenlanders ever possessed locally-owned ocean going ships. However, if they did, there certainly would have been none in existence by the thirteenth century, as local wood and driftwood could not support the construction of a vessel larger than the "six-oared boats" described in the written sources as being used for voyages within Greenland (probably similar in size and cargo capacity to the Shetlandic *sixern*, discussed in McGovern (1984). It has also been argued by Kristjánsson (1965) that the settlers could have made the initial voyages on 10- and 12-oared boats. These are "ocean going" in the sense that they were used to fish off the east coast of Greenland in early modern times. They were comparatively thin-hulled, clinker-built, open wooden boats, and were probably some of the most valuable (and difficult to replace) possessions of the Norse Greenlanders. Trans-Atlantic trade was carried by larger cargo ships and was organized by the Norwegian kings who maintained a commercial monopoly. *The Kings Mirror* describes the trade:

> *But in Greenland it is this way, as you probably know, that whatever comes from other lands is high in price, for this land lies so distant from other countries that men seldom visit it. And everything that is needed to improve the land must be purchased abroad, both iron and all the timber used in building houses. In return for their wares the merchants bring back the following products: buckskin, or hides, sealskins, and rope of the kind that we talked about earlier which is called leather rope and is cut from the fish called walrus, and also the teeth of the walrus.* (Larsen trans. 1917, *The King's Mirror-Speculum Regale-Konungs Skuggsjá*:142).

Summer drift ice in the eighteenth and nineteenth centuries greatly affected European contacts with Greenland, with whalers and early explorers generally avoiding the ice-filled fjords of the southwest coast. The relative lack of summer drift ice in the former Western Settlement area facilitated the establishment of a mission in 1721 by the Norwegian Hans Egede (1686-1758). Egede had hoped to find the lost Norse colonies.

When he did not, he began to work among the Inuit. An interesting aside is that, in translating the Lord's Prayer he judged that "Give us this day our daily bread" was best rendered as "Give us this day our daily common seal". Egede also founded the administrative capital of colonial and modern Greenland in the outer fjords of the former Western Settlement at Godthåb (now Nuuk) well north of the summer sea-ice limit.

For the Norse Greenlanders, the religious, administrative, and economic heart of their settlement was established early in the Brattahlið-Hvalsey-Garðar area, where the Bishop's manor and major chiefly farms were located; a zone today often impacted by the summer ice. The marine impacts of the onset of regular summer drift ice were not fatal; the last contemporary written record recording overseas contact dates to 1408 (see Fig. 12) and radiocarbon evidence suggests the Eastern Settlement survived into the mid-fifteenth century (Arneborg, 1996, 2000). However, a change in summer ice conditions certainly would have imposed additional costs and hazards on both local and trans-Atlantic travel as well as displacing common seal populations.

Figure 12. The ruin of Hvalsey church in the Eastern Settlement (located near modern-day Qaqortoq). The last written record giving contemporary information concerning the Greenland Norse is to be found in an entry in the *Icelandic Annals* for 1408. This documents the wedding of Sigriður Björnsdóttir and Thorsteinn Ólafsson, both from Iceland, on 16 September 1408 at Hvalsey. Photograph A.E.J. Ogilvie, 2008.

Since grain growing was probably never economically viable in Norse Greenland, the pastoral farming economy based upon herding of cattle, sheep, goats, horses, and (a few) pigs (the latter fed with marine food – Arneborg, pers. comm.) ultimately depended upon the productivity of pasture vegetation (Amorosi et al. 1998). Pasture productivity is affected by multiple variables, including soil nutrient levels and exposure, but temperature (both annual and within the summer growing season) and soil moisture levels have been demonstrated to be the most critical factors (Jakobsen 1987, Jakobsen

1991, Adderley and Simpson 2006). For further discussion of soils in southwestern Greenland, see also Rutherford 1995. The terrestrial ecosystem would also have been significantly affected by summer drift ice. The topography of much of the Eastern Settlement is marked by steep-sided fjord systems with most level pasture areas often close to the shore, creating special vulnerabilities to drift ice cooling effects. Sea ice reduces ground-level temperature on shore when it appears in significant amounts, depressing pasture growth and productivity when it appears during the short summer growing season. Such impacts have been widespread in northern Iceland when summer sea ice has arrived close in to the shore (Friðriksson 1969, Ogilvie 2005, 2008). The late-sixteenth century account by Oddur Einarsson, noted above, makes this point eloquently.

> *It makes a great difference at what time of year the ice comes. In the autumn, and at the time of winter solstice, when the frost has already got into the ground and there is snow cover, its presence does less damage. But during the spring and summer, when the weather is becoming milder, the ice invariably brings disaster with it, because that is when it has the greatest power and the grass is most adversely affected. The northerners are thus far worse off than the southerners who never see this ice*…..(Oddur Einarsson *Qualiscunque descriptio Islandiae* c. 1593, trans. Ogilvie 2005:272).

Summary

Research currently underway in the Eastern Settlement area by interdisciplinary teams coordinated by the Danish National Museum in cooperation with the National Greenland Museum and Archives (Nuuk) will soon expand our understanding of patterns of Norse settlement and subsistence, human impacts, and also climate impacts, in this region in the near future. In the meantime, the data currently available suggest that something occurred to change Norse hunters' access to common seals in the latter half of the thirteenth century in several parts of the Eastern Settlement, but not in the Western Settlement area. On the whole, the palaeoclimatic records noted above tend to support a mid- to late-thirteenth century transition point from a largely open water summer marine environment in Denmark Strait. Thus, at present, the most likely hypothesis for changes in seal-hunting patterns seems to be the influence of climate change and a transition to conditions of increased summer drift ice.

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Literature Cited

Adderley, W.P., and I.A. Simpson. 2006. Soils and palaeo-climate based evidence for irrigation requirements in Norse Greenland. Journal of Archaeological Science 33: 1666-1679.

Amorosi, T. 1992. Climate impact and human response in Northeast Iceland: archaeological investigations at Svalbard, 1986-1988. *In* C.D. Morris and D.J. Rackham (Eds.). Norse and Later Settlement and Subsistence in the North Atlantic. University of Glasgow, Glasgow:33-41.

Amorosi, T. 1996. Zooarchaeology and Gobal Change in Iceland. Unpublished PhD dissertation. Hunter College, CUNY.

Amorosi, T., P.C. Buckland, K.J. Edwards, I.L. Mainland, T.H. McGovern, J.P. Sadler and P. Skidmore. 1998. They did not live by grass alone: the politics and palaeoecology of animal fodder in the North Atlantic region. Environmental Archaeology 1:55-62.

Amundsen, C.P. 2003. Early medieval fishing activity in the Kola Peninsula. *In* A.F. Guzman, O.J. Polaco and F.J.Aguilar (Eds.) Presence of the Archaeoichthyology in Mexico. Proceedings of the 12th meeting of the Fish Remains Working Group of the International Council for Archaeozoology. Guadalajara, Jalisco, Mexico 4-12 September 2003:11-18.

Andrews, J.T., D. Darby, D.Eberle, A.E. Jennings, M. Moros and A.E.J.Ogilvie. 2009. A robust, multisite Holocene history of drift ice off northern Iceland: implications for North Atlantic climate. The Holocene, 19, 1:71-77.

Armit, I. 1996. The Archaeology of Skye and the Western Isles. University of Edinburgh Publications, Edinburgh.

Árnason, Jón. 1956. Íslenzkar þjóðsögur og æventýri. Ný útgáfa (vols. 1-2); Nýtt safn (vols. 3-6). *In* Árni Böðvarsson and Bjarni Vilhjálmsson (Eds.). 6 vols. Bókaútgáfan Þjóðsaga, Reykjavík.

Arneborg, J. 1996. Burgunderhuer, baskere og døde nordboer i Herjolfsnæs, Grønland. [Burgundian caps, Basques and dead Norsemen at Herjolfsæs, Greenland]. Pp. 75-83, *In* S. Hvass (Ed.). Nationalmuseets Arbeidsmark 1996 National Museum, Copenhagen, Denmark, 219pp.

Arneborg, J. 2000. Greenland and Europe. *In* W.W. Fitzhugh and E.I. Ward, E.I. (Eds.). Vikings: the North Atlantic Saga. Smithsonian Institution Press, Washington and London: 281-284.

Arneborg, J., J. Heinemeier, N. Lynnerup, H.L. Nielsen, N. Rud, and Árny E Sveinbjörnsdóttir. 1999. Change of diet of the Greenland Vikings determined from stable carbon isotope analysis and C14 dating of their bones. Radiocarbon 41:157-168.

Barlow, L.K. 1994. Evaluation of Seasonal to Decadal Scale Deuterium and Deuterium Excess Signals, GISP2 Ice Core, Summit, Greenland, AD 1270-1985. PhD dissertation. University of Colorado, Boulder.

Barlow, L.K., J.P. Sadler, A.E.J. Ogilvie, P.C. Buckland, T. Amorosi, J.H. Ingimundarson, P. Skidmore, A.J. Dugmore and T.H. McGovern. 1997. Interdisciplinary investigations of the end of the Norse Western Settlement in Greenland. The Holocene 7:489-499.

Benediktsson, Jón (Ed.) 1950. Arngrimi Jonæ Opera Latine Conscripta, Vol I. *In* Helgason, Jón (Ed.) Bibliotheca Arnamagnaeana, Vol. IX, Ejnar Munksgaard, Copenhagen.

Benediktsson, Jón (Ed.) 1968. Íslendingabók. Landnámabók. Íslenzk fornrit I, Hið íslenzka fornritafélag, Reykjavík, 525 pp.

Bergthórsson, Páll 1969. An estimate of drift ice and temperature in Iceland in 1000 years. Jökull 19: 95-101.

Bigg, M. 1981. Harbour Seal. *In* Ridgway, S., and Harrison, R. (Eds.). Handbook of Marine Mammals: Volume 2 Seals. Academic Press, London:1-27.

Buch, E. 2000. A monograph on the physical oceanography of the Greenland waters. Danish Meteorological Institute Scientific Report 00-12:1-104.

Church, M.J., S.V. Arge, S. Brewington, T.H. McGovern, J.M. Woollett, S. Perdikaris, I.T. Lawson, G.T. Cook, C. Amundsen, R. Harrison, K. Krivogorskaya and E. Dunbar. 2005. Puffins, pigs, cod, and barley: Paleoeconomy at Undir Junkarinsfløtti, Sandoy, Faroe Islands. Environmental Archaeology 10:179-197.

Clark, J.G.D. 1946. Seal-hunting in the Stone Age of north-western Europe: a study in economic prehistory. Proc. Prehist. Soc. 2:12-48.

Degerbøl, M. 1934. Animal bones from the Norse ruins at Brattahlið. Meddelelser om Grønland 88:149-155.

Degerbøl, M. 1941. The osseous material from Austmannadal and Tungmeralik. Meddelelser om Grønland 89:345-354.

Deitrich, K.A., W.P. Patterson, J.T. Andrews, A.E. Jennings and A.E.J. Ogilvie. 2004. Quantitative reconstructions of near-shore environments over the last 2000 years in Vestfirðir, northern Iceland: Evidence from high resolution stable isotope analyses of molluscs. *In* 34th International Arctic Workshop, Program with Abstracts. INSTAAR, Boulder, Colorado, 10-13 March 2004:47-49.

Deitrich, K.A., W.P. Patterson, J.T. Andrews, A.E. Jennings and A.E.J. Ogilvie. 2005. Quantitative reconstructions of near-shore environments over the last 2000 years in Vestfirdir, NW Iceland: evidence from high-resolution stable isotope analyses of molluscs. *In* 35th International Arctic Workshop, Program with Abstracts. University of Alberta, Edmonton, Alberta, Canada, 9-12 March, 2005.

Dugmore, A.J., C. Keller, and T.H. McGovern. 2007. Reflections on climate change, trade, and the contrasting fates of human settlements in the North Atlantic islands. Arctic Anthropology 44(1):12-37.

Dugmore, A.J., C. Keller, T.H. McGovern, A.F. Casely, and Smiarowski, K. 2008. Norse Greenland settlement and limits to adaptation. *In* A. Wawn (Ed.). Social Resilience and Limits to Adaptation. Cambridge University Press, Cambridge. In press.

Edvardsson, Ragnar, and T.H. McGovern. 2005. Archaeological excavations at Vatnsfjörður 2003-04. Archaeologica Islandica 4: 16-31.

Einarsson, Oddur 1971. Íslandslýsing. Qualiscunque description Islandiæ. Introduction by Jón Benediktsson. Bókaútgáfa Menningarsjóðs, 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.

Fenton, A. 1978. The Northern Isles: Orkney and Shetland. John Donald Publishers.

Friðriksson, Sturla 1969. The effects of sea ice on flora, fauna and agriculture. Jökull 19: 146-57.

Gearheard, S., W. Matumeak, I. Angutikjuag, J. Maslanik, J., H.P. Huntington, J. Leavitt, D. Matuemeak Kagac, G. Tigullaraq, and R.G.Barry. 2006. "It's Not That Simple": A collaborative comparison of sea ice environments, their uses, observed changes, and adaptations in Barrow, Alaska, USA and Clyde River, Nunavut, Canada. Ambio 35 (4):204-212.

Godtfredsen, A. B. and T. Møberg, T. 2004. Nipisat – a Saqqaq culture site in Sisimiut, Central West Greenland. Meddelelser om Grønland Man and Society 31. Copenhagen.

Guðmundar saga biskups Arasonar 1878. In Biskupa Sögur II, 5.

Guldager, O. 2002. Brattahlid reconsidered. Some thoughts on the social structure of medieval Norse Greenland, and the location of Brattahlid. Archaeologia Islandica 2:74 – 97.

Hakluyt's Voyages 1928. Vol. 1 of the Foreign Voyages and Vol. 9 of the Principal Navigations. First published 1598. London, Toronto, New York.

Halldórsson, Ó. 1978. Grænland í miðaldarítum. Sögufélag, Reykjavik.

Härkönen, T., S. Brasseur, J. Teilmann, C. Vincent, R. Deitz, K. Abt and P. Reijnerds. Status of grey seals along mainland Europe from the southwestern Baltic to France. NAMMCO Scientific Publications Vol. 6: 57-68.

Harrison, R. The medieval trading station at Gásir, Eyjafjörður, N Iceland: Interim Report of faunal analysis from the 2006 Excavations. NORSEC lab report # 30. *In* Excavations at Gásir 2006: An Interim Report/Framvinduskýrsla. Lilja Björk Pálsdóttir and Howell Roberts (Eæsds). FS355 -010710, July 2007, Reykjavík, Iceland.

Harrison, R., H.M. Roberts, and W.P. Adderley. 2008a. Gásir in Eyjafjörður: International Exchange and Local Economy in Medieval Iceland. 2008. Journal of the North Atlantic 1 (1):99-119. Publisher: Eagle Hill Foundation.

Harrison, R., M. Hicks, P. Colligan, and A. Schreiner. 2008b. Preliminary Assessment of the faunal remains from the 2007 Midden Excavation in Eyri, Westfjords, NW Iceland. May 2008, NORSEC lab report 42., CUNY, New York.

Hebsgaard, M.B., M. Thomas P. Gilbert, J. Arneborg, P. Heyn, M.E. Allentoft, M. Bunce, K. Munch, C. Schweger, and E. Willerslev. 2009. "The Farm Beneath the Sand" – and archaeological case study on ancient "dirt" DNA. Antiquity 83 (2009): 430-444.

Holtsmark, A. 1956-78. Kongespeillitteratur. Kulturhistorisk Leksikon for Nordisk Middelalder 9, Rosenkilde og Bagger, Copenhagen, col. 61-68.

Huntington, H.P. and S.E. Moore, S.E. eds. 2008. Assessing the impacts of Arctic change on marine mammals. Ecological Applications 18, Supplement Arctic Marine Mammals. March 2008, S1-S2.

Jakobsen, N.K. 1987. Studies on soils and potential for soil erosion in the sheep farming area of South Greenland. Journal of Artic and Alpine Research 19: 498-507.
Jakobsen, B.H. 1991. Soil resources and soil erosion in the Norse settlement area of Østerbygden in Southern Greenland. Acta Borealia 1: 56-68.
Jennings A.E., and N.J. Weiner, N.J. Environmental change in eastern Greenland during the last 1300 years: evidence from foraminifera and lithofacies in Nansen Fjord 68N. The Holocene 6 (2):179-191.
Jensen, K.G., A. Kuijpers, A., N. Koc, and J. Heinemeier. 2004. Diatom evidence of hydrographic changes and ice conditions in Igaliku Fjord, South Greenland, during the past 1500 years. The Holocene 14 (2):152-164.
Jónsson, Finnur, (Ed.) 1930. Det gamle Grønlands beskrivelse af Ívar Bárðarson (Ivar Bårdsson). Udgiven efter håndskriftene, Copenhagen.
Jónsson, Finnur, (Ed.) 1920. Konungs Skuggsjá Speculum Regale, Udgivet efter håndskriftene af det kongelige nordiske oldskriftselskab, Copenhagen.
King, J. 1983. Seals of the World. Comstock Publishing Associates, Ithaca, New York.
Kristjánsdóttir, Greta Björk 2005. Holocene Changes in Climate, Environment, and Ocean Reservoir Age on the Iceland Shelf. PhD thesis. Department of Geological Sciences and INSTAAR, University of Colorado, Boulder.
Kristjánsson, Lúðvík. 1965. Grænlenzki landnemaflotinn og breiðfirzki báturinn. Árbók Hins íslenzka fornleifafélags 1964 (1965):20-68.
Kristjánsson, Luðvik 1980. Íslenzkir sjávarhættir 1, Bókaútgáfa Menningarsjóðs, Reykjavik.
Larson, L.M. (Trans.) 1917. The King’s Mirror (Speculum Regale-Konungs Skuggsjá). Translated from the Old Norse with introduction and notes by Laurence Marcellus Larson. Twayne Publishers, Inc., The American-Scandinavian Foundation, New York.
Lassen, S.J., A. Kuijpers, H. Kunzendorf, G. Hoffman-Wieck, N. Mikkelsen, and P. Konradi. 2004. Late-Holocene Atlantic bottom-water variability in Igaliku Fjord, South Greenland, reconstructed from foraminifera faunas. The Holocene 14 (2):165-171.
Lynnerup, N. 1996. Paleodemography of the Greenland Norse. Arctic Anthropology, 33, No.2, 122-136.
McGovern, T.H. 1981. The economics of extinction in Norse Greenland. *In* T.M.L Wigley, M.J. Ingram, and G. Farmer (Eds.). Climate and History. Studies in Past Climates and their Impact on Man. Cambridge University Press, Cambridge:404-433.
McGovern, T.H. 1984. From zooarchaeology to paleoeconomy: a case from Norse Greenland, MASCA Journal 3(2):36-40.
McGovern, T.H. 1985a. The arctic frontier of Norse Greenland. *In* S. Green, and S. Perlman (Eds.). The Archaeology of Frontiers and Boundaries, Academic Press, New York, 275-323.
McGovern, T.H. 1985b. Contributions to the Paleoeconomy of Norse Greenland. Acta Archaeologica 54:73-122.
McGovern, T.H., G.F. Bigelow, T. Amorosi, and D. Russell. 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. 1991. Climate, correlation, and causation in Norse Greenland. Arctic Anthropology 28(2):77-100.

McGovern, T.H. 1992a. Bones, buildings, and boundaries: Paleoeconomic approaches to Norse Greenland. *In* C.D. Morris, and J. Rackham (Eds.). Norse and Later Settlement and Subsistence in the North Atlantic. Glasgow University Press, Glasgow:157-186.

McGovern, T.H. 1992b. Zooarchaeology of the Vatnahverfi. *In* C.L. Vebaek (Ed.). "Vatnahverfi", Meddelelser om Grønland Man and Society 17:93-107.

McGovern, T.H., G.F.Bigelow, T. Amorosi, J.M. Woolett, S. and Perdikaris. 1993. Animal bones from E17at Narsaq. *In* C.L Vebaek (Ed.). "Narsaq- A Norse Landnama Farm", Meddelelser om Grønland, Man and Society 18:134-147.

McGovern T.H., T. Amorosi, S. Perdikaris, and J.M. Woollett. 1996. Zooarchaeology of Sandnes V51: economic change at a chieftain's farm in West Greenland. Arctic Anthropology 33(2):94-122.

McGovern, T.H., S. Perdikaris, and C.Tinsley. 2001. Economy of landnám: the evidence of zooarchaeology. *In* A. Wawn and Þórunn Sigurðardóttir (Eds.). Approaches to Vinland. Sigurður Nordal Institute Studies 4, Reykjavik:154-165.

McGovern, T.H., S. Perdikaris, Á Einarsson, and J. Sidell. 2006. Coastal connections, local fishing, and sustainable egg harvesting, patterns of Viking age inland wild resource use in Mývatn District, northern Iceland. Environmental Archaeology 11(1): 102-128.

McGovern T.H., K. Smiarowski, and Albina Palsdóttir. 2006. Preliminary report of a medieval Norse archaeofauna from Brattahlið North Farm (KNK2629) Qassiarsuk, Greenland. NORSEC Laboratory Reports 34 (xw**e**b.g**e**os.**e**d.ac.uk/~nabo/publications/labreports/norsec).

McGovern, T.H., O. Vésteinsson, A. Friðriksson, M.J. Church, I.T. Lawson, I.A. Simpson, Á Einarsson, A.J. Dugmore, G.T. Cook, S. Perdikaris, K.J. Edwards, A.M. Thomson, W.P. Adderley, A.J. Newton, G. Lucas, Ragnar Edvardsson, Oskar Aldred, and E. Dunbar. 2007. Settlement, sustainability, and environmental catastrophe in Northern Iceland. American Anthropologist 109 (1):27-51.

Meldgaard, M. 1995. Resource pulses in a marine environment: a case study from Disko Bugt, West Greenland. *In* A. Fisher, A. (Ed.). Man and Sea in the Mesolithic. Oxbow Books:361-68.

Meldgaard, M. 2004. Ancient harp seal hunters of Disko Bay. Subsistence and settlement at the Saqqaq culture site Qeqertasussuk (2400-1400 BC) West Greenland. Meddelelser om Grønland, Man and Society 30, 189 pp.

Moros, M., Jensen, K.G., Kuijpers, A. 2006. Mid-to late Holocene hydrological and climatic variability in Disko Bugt, central West Greenland. *The Holocene* 16 (3):357-367

Murray, M. 2005. Prehistoric use of ringed seals: a zooarchaeological study from Arctic Canada. Environmental Archaeology 10(1):34-62.

Ogilvie, A.E.J. 1984. The past climate and sea-ice record from Iceland. Part 1: Data to AD 1780. Climatic Change 6:131-152.

Ogilvie, A.E.J. 1991. Climatic changes in Iceland A.D. c. 1500 to 1598. *In* G.F. Bigelow (Presentor). The Norse of the North Atlantic. Acta Archaeologica Vol. 61-1900. Munksgaard, Copenhagen:233-251.

Ogilvie, A.E.J. 1992. Documentary evidence for changes in the climate of Iceland, A.D. 1500 to 1800. *In* R.S. Bradley, and P.D. Jones, P.D. (Eds.). Climate Since A. D. 1500, Routledge, London and New York: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* B. Frenzel (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, 25-43.

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

Ogilvie, A.E.J. 2008. Bréf sýslumanna til stiftamtmanns og amtmanns: Environmental images of nineteenth-century Iceland from official letters written by district sheriffs. *In* M. Wells (Ed.). The Discovery of Nineteenth Century Scandinavia as Reflected in Travel-Writing, Essays, Letters and Fiction Written by Scandinavians and Others. Norvik Press, Norwich.

Ogilvie, A.E.J. and Ingibjörg Jónsdóttir. 2000. Sea ice, climate and Icelandic fisheries in historical times. Arctic 53 (4):383-394.

Ogilvie, A.E.J., and Trausti Jónsson. 2001. '"Little Ice Age" research: A perspective from Iceland'. Climatic Change 48:9-52.

Ogilvie, A.E.J., L.K. Barlow and A.E. Jennings. 2000. North Atlantic climate c. AD 1000: Millennial reflections on the Viking discoveries of Iceland, Greenland and North America. Weather 55:34-45.

Pálsdóttir, A. H., M.E. Gorsline, and T.H. McGovern. 2008. Archaeofauna from Vatnsfjörður, Westfjords, Iceland – Interim report 2003-2007. May 2008. NORSEC lab report 43., CUNY, New York

Perdikaris, S. and T.H. McGovern. 2007. Walrus, cod fish, and chieftains: Intensification in the Norse North Atlantic. *In* T.L. Thurston and C.T. Fisher (Eds.). Seeking A Richer Harvest: The Archaeology of Subsistence Intensification, Innovation, and Change. Springer Science and Business Media, New York:193-216.

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

Riedman, M. 1990. The Pinnipeds: Seals, Sea Lions, and Walruses. University of California Press, Oxford.

Ridgway, S.H. and R.J. Harrison (Eds.). 1981. Handbook of Marine Mammals, vol. 2: Seals, Academic Press Inc., Ltd, London.

Roncaglia, L., and A. Kuijpers. 2004. Palynofacies analysis and organic-walled dinoflagellate cysts in late Holocene sediments from Igaliku Fjord, South Greenland. The Holocene 14 (2):172-184.

Rutherford, G.K. 1995. Soils of some Norse settlements in Southwestern Greenland. Arctic 48 (4):324-328.

Sergeant, D.E. 1991. Harp Seals, Man and Ice. Canadian Special Publications of Fisheries and Aquatic Sciences no. 114. Springer, Netherlands.

Sigmarsson, Einar. 2003. Glímt við gamla gátu. Hver er höfundur Qualiscunque description Islandiæ? (Taking another look at an old riddle: Who is the author of Qualiscunque description Islandiæ?) Saga XLI 1: 97-133.

Simpson, I.A., W.P. Adderley, G. Guðmundsson, M. Hallsdóttir, M.Á. Sigurgeirsson, and M. Snæsdóttir. 2002. Land management for surplus grain production in early Iceland. Human Ecology 30:423-443.

Simpson, I. A., O. Vésteinsson, W.P. Adderley, and T.H. McGovern, T.H. 2003. Fuel resources in landscapes of settlement. Journal of Archaeological Science 30: 1401-1420.

Simpson, I. A., G. Guðmundsson, A.M. Thomson, and J. Cluett. 2004. Assessing the role of winter grazing in historic land degradation, Mývatnssveit, northeast Iceland. Geoarchaeology 19:471-503.

Smiarowski, K., Albína Pálsdóttir, and T.H. McGovern. 2007. Preliminary assessment report of the archaeofauna from KNK 203 (E 74), a Norse Farm in the Eastern Settlement, Greenland. NORSEC Laboratory Report 39 (xw**e**b.g**e**os.**e**d.ac.uk/~nabo/publications/labreports/norsec/Norsec39E74PrelimZooarchAssessment.pdf)

Storå, J. 2002. Seal hunting on Ajvide. A taphonomic study of seal remains from a pitted ware culture site on Gotland. *In* G. Burenhult, G. (Ed.). Remote Sensing. Applied techniques for the study of cultural resources and the localization, identification and documentation of sub-surface prehistoric remains in Swedish archaeology. 1984/1997/2002. Volume II: Archaeological investigations, remote sensing case studies and osteo-anthropological studies. Department of Archaeology, Stockholm University, Stockholm, 387-428.

Stroeve, J., M.M. Holland, W. Meier, W., T. Scambos, and M.C. Serreze. 2007. Arctic sea ice declines faster than forecast. Geophysical Research Letters, 34 L09501, doi: 10.1029/2007GL029703, 2007.

Stroeve, J., M. Serreze, S. Drobot, S. Gearheard, M.M. Holland, J. Maslanik, W. Meier, and T. Scambos. 2008. Arctic sea ice plummets in 2007, EOS, 89, 2, 13-14.

Taylor, J.T. et al. 2005. Continued Excavations at the Farm Mound at Eyri, Ísafjörður:Excavation report, FS267-03232, FSÍ, Reykjavík, Iceland.

Vibe, C. 1967. Arctic animals in relation to climatic fluctuations. Meddelelser om Grønland 170*(5).*

Wadhams, P. 2000. Ice in the Ocean. Gordon and Breach Publications, London, 364pp.

Woollett, J. 1997. Feasts of winter: zooarchaeological perspectives on Labrador Inuit subsistence during the contact period. *In* M.A.P. Renouf, M.A.P. (Ed.). Proceedings of the North Atlantic Biocultural Organization Conference. A Summit of the Sea Conference for the Cabot 500 Celebrations. St. John's, Newfoundland, May 1997.

Woollett, J. M. 1999. Living in the narrows: Labrador Inuit subsistence in Hamilton Inlet. World Archaeology 31 (1):370-387.

Woollett, J. M. 2003. An Historical Ecology of Labrador Inuit Culture Change. Ph.D. dissertation. Dept. of Anthropology, The Graduate School and University Center, City University of New York.

Woollett, J. M., A. Henshaw, and C. Wake. 2000. Palaeoecological implications of archaeological seal bone assemblages: case studies from Labrador and Baffin Island, Arctic 53(4):395-413.

Woollett, J. M. 2007. Labrador Inuit subsistence in the context of environmental change: an initial landscape history perspective. American Anthropologist 109(1): 69-84.