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Norse Greenland Settlement: Reflections on Climate Change, Trade, and the Contrasting Fates of Human Settlements in the North Atlantic Islands

Andrew J. Dugmore, Christian Keller, and Thomas H. McGovern

Abstract. Changing economies and patterns of trade, rather than climatic deterioration, could have critically marginalized the Norse Greenland settlements and effectively sealed their fate. Counter-intuitively, the end of Norse Greenland might not be symptomatic of a failure to adapt to environmental change, but a consequence of successful wider economic developments of Norse communities across North Atlantic. Data from Greenland, the Faroe Islands, and medieval Iceland is used to explore the interplay of Norse society with climate, environment, settlement, and other circumstances. Long term increases in vulnerability caused by economic change and cumulative climate changes sparked a cascading collapse of integrated interdependent settlement systems, bringing the end of Norse Greenland.

Introduction

At a time when the effects of global climate change can be seen to be taking place, there is a pressing need to assess how these might affect human society.[1] The extent to which climate changes exacerbate environmental degradation, drive settlement collapse, cause famine, spur migrations, or trigger conflict over resources has received widespread attention (e.g., Diamond 2005; Fagan 2000, 2004; Linden 2006). It is clear that climate change, and the weather it produces, can have a wide range of impacts, many negative, some positive, but all with the potential to affect human security. Crucially, however, opinions differ as to the importance to human societies of climate on its own and in comparison to unrelated processes of social, political, and economic change (Diamond 2005). Furthermore, even if climate change can be shown to have produced a direct impact (for instance crop failure or livestock mortality), perhaps the most important question of all is why people do not (or cannot) adapt and either avoid or mitigate the bad effects of the weather. As with so many other environmentally related issues that cut across disciplinary boundaries, assessments of relative emphasis, sensitivity, thresholds, adaptation, and response are vital. This paper reconsiders the case of Norse Greenland and the end of the settlements in the early part of the Little Ice Age (Grove 2001; Jones 1986). For this iconic example of settlement desertion widely associated with climate change

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and an inability to adapt, the paper explores both the nature of climate change and unrelated economic factors that may have played crucial, if not dominant roles, in determining the ultimate fate of the Norse Greenlanders.

The Norse in the North Atlantic

The Norse settlement of the Faroe Islands, Iceland, and Greenland (Fig. 1) began between the early ninth and late tenth centuries A.D. and, although comparatively recent, it spans a sufficiently long period to include notably different climatic episodes and major cultural changes (Grove 1988; Jones 1986). When considered as a whole, the North Atlantic islands permit the analysis of human colonization, adaptation, and long-term settlement undertaken by similar groups of people (Viking Age settlers from northwestern Europe) in contrasting island environments across significant climatic gradients (Edwards et al. 2004). A pan-Atlantic view can consider key aspects of people's experiences of, and responses to, different environmental and cultural challenges and, ultimately, their very different experiences of success and failure (Barlow et al. 1997; Karlsson 2000; McGovern and Perdikaris 2000). Importantly, historical context and the culture of the Scandinavian settlers of North Atlantic islands are well known, due to a unique host of medieval manuscripts (see Friðriksson 1994; Karlsson 2000; Kristjánsson 1993; Ólasson 1998; Vasey 1996; Vésteinsson 2000). High quality regional environmental data are available from Greenland ice cores and accurate correlation of multiple data sources (historical, archaeological, and environmental data from landforms, soils, sediments, and peats) is possible to very high standards through the use of both radiocarbon and tephrochronology, an environmental dating based on layers of volcanic ash (e.g., Buckland et al. 1991; Dugmore, Larsen, and Newton 2004; Meeker and Mayewski 2002; Thórarinsson 1967, 1975, 1981). Quite remarkable new perspectives have also been gained from faunal records based on hundreds of thousands of identified bones from archaeological contexts that give unrivalled insights into the subsistence and economies of the past (e.g., Church et al. 2005; McGovern 2000; McGovern, Perdikaris, and Tinsley 2001; Perdikaris 1999; Perdikaris and McGovern in press a).

The Norse colonies in Greenland were established shortly before the year 1000 A.D, the last documented outside contact was in 1409 A.D., and by the sixteenth century A.D. the Norse Greenlanders had disappeared in circumstances that are unresolved, but are thought to have involved an interplay between a range of factors including climatic deterioration, environmental degradation, maladaptation, economic marginalization, and conflict with the Inuit (Arneborg 2002, 2003a, 2003b; Gulløv 2004:273–275, 277; McGovern 2000; Petersen 2000; Seaver 1996). In addition, the "Great Plague" that devastated Iceland for the first time in 1402–1403 A.D. created a demographic deficit in Iceland that could be filled from abroad (Karlsson 1996). Alternatively, this epidemic might have reached Greenland a decade later, with terminal consequences for the Norse.

Coherent syntheses can be fashioned that combine all these and other explanations (such as raids by Barbary pirates). In the process of finding consensus, however, it is possible that important insights may be lost, including the distinction between factors that could have increased the fundamental vulnerability of the Norse settlements to extinction (and made their ultimate fate inevitable)

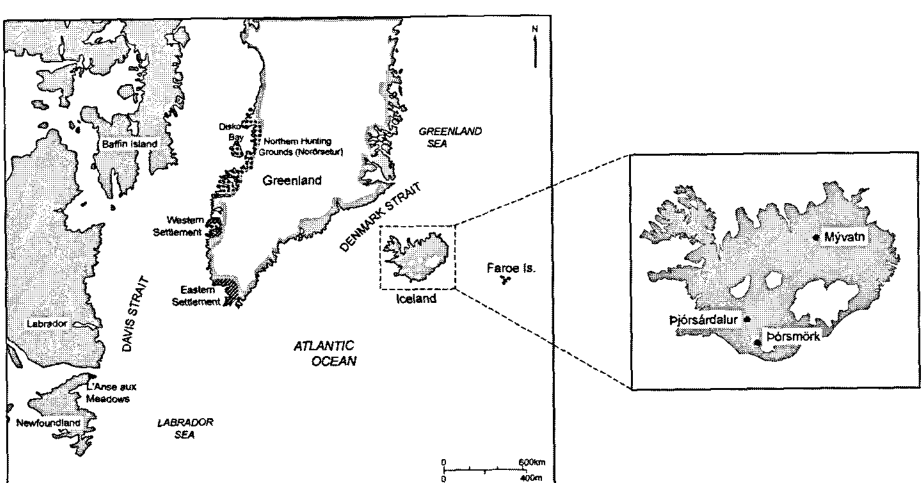

Figure 1. The North Atlantic showing places referred to in the text.

and the final trigger for extinction (an event, or events that under other circumstances might not have had such decisive effects).

It is generally accepted that initial settlement was boosted by climatic conditions that were, on the whole, more favorable to the Norse than those of the fourteenth century A.D. onwards (Barlow et al. 1997; Ogilvie and McGovern 2000). With the local onset of cooler conditions, the increasing extent of pack ice could have seriously affected shipping and compromised hunts for marine mammals, in particular forays into the northern hunting grounds for walrus. Hand in hand with the development of more extensive pack ice, the shortened growing seasons, reduced fodder production, longer over-wintering periods, environmental degradation, and more demanding conditions for raising domestic animals could have made the subsistence base of the Norse more precarious than it had been at the time of settlement (Buckland et al. 1996). In combination with an inability to adapt, these all-encompassing climatically driven changes could be all that really mattered, as they alone could have made the Norse Greenlanders' way of life so marginal that it was simply a question of *when* the colonies failed rather than *if*. This inevitable descent to destruction might have been accelerated by cultural factors (McGovern 1994). An inability or unwillingness to adapt, to adopt an Inuit lifestyle, or to embrace other radical change, may have critically reduced chances for survival, and accelerated the final collapse. Maladaptation could have taken a variety of forms. There is no evidence that the Norse Greenlanders adopted Inuit Arctic-adapted technology, such as the toggle harpoon and the kayak. This failure to acquire Inuit technologies and related subsistence strategies that might have saved the Norse could be explained by intense cultural conservatism and the oppressive control of an elite who did not wish to see change that might have weakened their own position. In addition, violent conflict with the Inuit could have further compromised any possibility of cultural transmissions and the sharing of viable survival strategies (Petersen 2000). Other aspects of maladaptation could have included damaging or inappropriate applications by the Norse of their own pastoralist system. This could have included poorly managed grazing strategies that enhanced erosion, inappropriate mixes of livestock, and poor strategies for producing meat, dairy products, wool, and hides, as well as the unsustainable harvesting of wild resources (Fig. 2).

The argument for maladaptation and the impact of climatic deterioration rests upon the assumption that change of lifestyle was of fundamental importance. An alternative view is that these could be the wrong issues to emphasize. There might have been nothing fundamentally

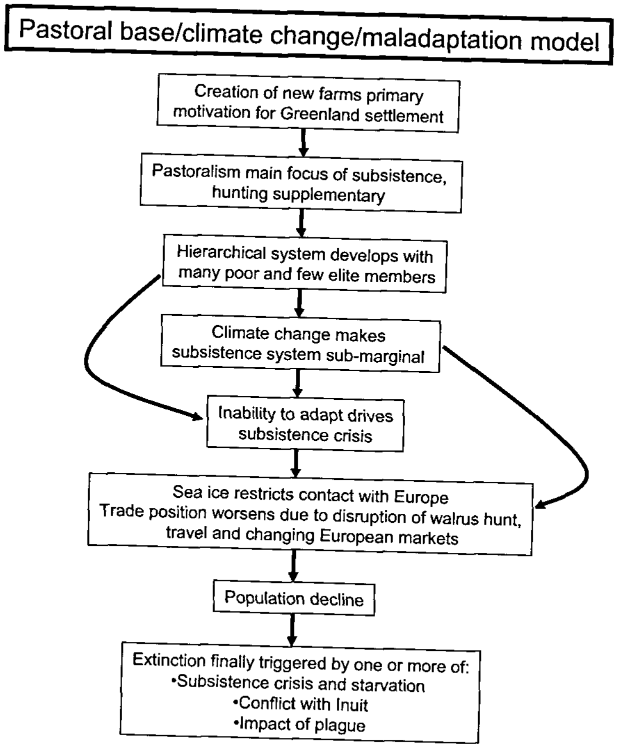

Figure 2. A conceptual model of Norse Greenland settlement highlighting the key roles of a pastoral focus, the impact of climate change, and an inability to adapt.

wrong with the Norse approach to subsistence in Greenland and it could have been adequate for survival if other circumstances had been different; specifically, if the economic viability of the settlements had not been eroded and the Norse population had not declined (Lynnerup 2003).

Motivations for the Norse Colonization of Greenland— Land Hunger or Hunting?

Indications of the likely priorities of the Norse in Greenland, and the balance between trade and subsistence may be gained from the circumstances of the initial colonization effort. A written account of Eirik the Red and the naming of Greenland, can be found in Íslendingabók [the Book of the Icelanders), a short chronicle of Iceland's early history, that was written between 1122 and 1133 A.D. by Ari Þorgilsson the Learned (Hreinsson 1997; Karlsson 2000). In it, the now famous story is told that:

> The land which is called Greenland was discovered and settled from Iceland. Eirik the Red was the name of a Breidafjord man who went out there from here and took land in settlement at the place which has ever since been called Eiriksfjord. He gave the land a name, and called it Greenland,

> arguing that men would go there if the land had a good name. . . . (Karlsson 2000:29)

Apparently on the strength of this "sales pitch" Eirik was able to mount a very large and successful colonization effort, and took over some of the best agricultural land at Brattahlið in what was to become the Eastern Settlement. Eirik and the other early chieftains are said to have divided the wilderness, providing names to fjords, mountains, and other natural features (often naming them after themselves) and thus bringing the new cultural landscape into being. The written sources for the settlement of Iceland which also mention Greenland (Islendingabók, Landnámabók [the Book of Settlement], Eiríks saga rauða [the Saga of Eirik the Red], Grænlendingasaga [the Saga of the Greenlanders]) stress the role of such land hungry chieftains seeking pastures for their imported domestic animals and access to a range of wild resources to support clients and reward new followers (Hreinsson 1997).

These sources were written centuries after the events described, and are clearly influenced by contemporary twelfth and thirteenth century A.D. elite politics and the need to retroactively inflate (or create) the role of notable ancestors. As Adolf Friðriksson and Orri Vesteinsson (2003) demonstrate Landnámabók's apparently authoritative fjord by fjord listing of first settlers in much of Iceland on closer analysis looks like retrospective guesswork based on etymological interpretations of place names occasionally reinforced by elements of local tradition and much rearranged to suit later political ends. If the Icelandic literary record is a strongly suspect source for the history of early settlement in Iceland, one may suspect that it may be an even more ill informed, selective, and heavily edited account of the early days of the Greenland settlement.

While scholars have long debated the historical value of these later medieval accounts of ninth to early eleventh century settlement, the Norse colonization is still usually read in the context of land-hunger, driving an expanding agricultural population to go to the very margins of the biogeographic viability of their inherited North Western European farming economy (e.g., McGovern et al. 1988). While the close association of later permanent farms in Greenland with patches of pasture vegetation (noted by all fieldworkers since the eighteenth century) does indicate the key role of farming based on domestic stock production in later time periods, we now have some reasons to doubt the conventional Viking Age settlement model, ultimately based upon the written accounts of the high Middle Ages.

Simple subsistence-based "land hunger" is unlikely for Icelanders in the late tenth to early eleventh centuries A.D. Recent research in Iceland demonstrates a clear need to radically revise earlier models that saw the initial settlement process as a slow trickle of individual chieftains and their households gradually moving inland from coastal enclaves (established just after the well dated Landnám tephra of A.D. 871+2). Tephra and radiocarbon dates indicate that deep inland areas in north Iceland were also settled directly after the Landnám tephra fall, with indications of early permanent farms as much as 100 km from the coast (McGovern et al. 2006; Vésteinsson, McGovern, and Keller 2002). These inland settlements at the then grassy highland edge of the dense birch woodlands (around 300–400 meters above sea level) are exactly contemporary with the better documented coastal settlements. The inland highland settlements in the Mývatn district of North Iceland (Fig. 1) appear to have "leapfrogged" over the heavily wooded lowland valley systems, whose ungrazed and pathless birch and willow thickets would have initially been unattractive farming country. When the northern valley systems were deforested and cleared for settlement in the later tenth to early eleventh centuries A.D. they were to provide some of the richest farm sites in Iceland, thus opening attractive settlement potentials just as Greenland was being settled.

The initial, probably fluid, phase of settlement in Iceland was over by the mid tenth century. By that time the Icelandic national assembly, the Althing, had been established in 930 A.D. and laws had been created to protect land holdings and privileges (Karlsson 2000) The land was divided and owned, but the broad holdings of the major families were very large and probably were not actually fully settled until much later (Vesteinsson, Mcgovern, and Keller 2002). There are few environmental signs of significant pressures on the land having developed in Iceland by the late tenth century and the Norse colonization of Greenland (Dugmore and Buckland 1991; Dugmore and Erskine 1994; Dugmore et al. 2000). In the most ecologically favorable areas, the dense indigenous woodland would have been opened up with inroads and clearings, so greatly increasing its utility. Even as newly cleared mid-valley farms were occupied and the initially broad magnate holdings became more fully settled, additional settlement in land subdivisions must have still been possible in Iceland, as this process of subdivision and planned settlement extended into later medieval times. Major landowners could have had powerful reasons to encourage additional settlement on their own estates as a way to increase their own power, wealth, and influence. In Iceland, settlement infrastructure including established farms with hayfields, breeding stocks of domesticated animals, and regional exchange mechanisms had been created, and were well established by the mid tenth century A.D. (McGovern et al. 2006). The concentration of power and privilege in the hands of a small elite had yet to happen and the disastrous civil conflicts of the thirteenth century A.D. Sturlungar Period were still way into the future (Karlsson 2000:79–82). In places such as south Iceland, abandonment of settlement sites in the upland margin had not yet begun, and lowland woodlands devoted to charcoal production were yet to be "worked out" (Dugmore et al. 2006). In short there seems to have been little in the way of a mass "land hunger" and few environmental "push factors" encouraging people to leave Iceland in search of living space in Greenland.

Any "push factors" existing in late tenth century A.D. Iceland were probably social rather than environmental. By 930 A.D. the *goðorð* or chieftainships, were established, courts set up, land claimed (if not settled), and the rules of competition established which would last until the civil wars of the mid thirteenth century A.D., which brought on the twilight years of the Icelandic Commonwealth. Relatively late colonizers in Iceland who were not part of the older (now landed) chieftainships, and who probably did not fit into the evolving set of regional *góði* to *bóndi* [chieftain to independent farmer] relationships, were in a sense thrown back into a pre-Viking Age situation of being excluded from the obvious sources of prestige and wealth, land and influence over clients.

By the mid tenth century A.D., Iceland was thus not so much over-populated as "over-chieftained." Sources of wealth that could gain prestige and honor for ambitious individuals and lineages were largely earmarked if not fully developed and contesting these claims could end in defeat and outlawry (as suggested in the very late and somewhat unreliable saga of Eirik the Red). In the late tenth century A.D., Greenland was therefore attractive to Icelanders not because of chronic land or subsistence shortage in Iceland, but because of a shortage of ways to gain prestige and honor in Iceland. Did the decision to settle Greenland spring entirely from Eirik's failed aggrandizement in Iceland, or was there background in an earlier "untold saga" relating to hunting and Arctic prestige goods rather than to the land-hungry chieftain farmers so extensively featured in the later written sources now familiar to us?

Pioneering Hunters?

Was there an "unofficial," undocumented, and perhaps socially unacceptable earlier occupation of Iceland and Greenland less tied to agricultural land and the demands of chieftainship? In several recent workshops, Adolf Friðriksson has hypothesized that some period of pre-agricultural exploration by hunters and scouts must have pre-dated the full scale (and high risk) recorded trans-Atlantic Landnám settlements by whole households and their domestic animals. Giving a new country an attractive name is not the same thing as exploring it, and it is hard to imagine any of the articulate, authoritative, and hard-headed women featured in the sagas as household managers and influential leaders in their own right consenting to uproot kin and servants, farming gear, family wealth, and precious domestic stock solely on the word of a (so far) failed upstart like Eirik.

Did groups of hunters precede the Norse farmers, providing detailed knowledge of land and resources and a vital initial economic base, thus significantly contributing to the success of the later Landnám before being conveniently forgotten by later scribes? Before the farmers came, were there brief but vital initial phases of exploration, exploitation, and occupation undertaken by Norse hunters in Iceland in the ninth century A.D. and in Greenland in the tenth century A.D.?

In southwest Iceland, the discovery of walrus bones (some newborn, suggesting a resident breeding walrus population) under the streets of modern Reykjavik, followed by finds of three nearly complete, expertly extracted walrus tusks, datable to just after the deposition of the Landnám tephra of 871±2 A.D., and left beneath the bench of a long hall less than 500m away, confirm the place name evidence suggesting multiple walrus hunting areas along the nearby Reykjanes peninsula (McGovern, Perdikaris, and Tinsley 2001). Walrus colonies in Iceland would have provided an immediate return in low-bulk, high- value Viking age prestige goods for hunters, while large colonies of nesting sea birds (recalled as initially "unwary and easily killed" by later texts) would have provided provisions. Did mid to late tenth century hunters (probably well below chiefly status) provide guides or at least reliable travel reports for the well recorded chiefly settlers? In any case, the Icelandic walrus populations of the south coast do not seem to have survived after the tenth century A.D.

The Norse discovery of Greenland's massive populations of walrus and other marine mammals, plus fur bearing animals and rare items such as falcons and narwhal tusks would have thus presented attractive economic opportunities to any Icelandic hunters by the mid tenth century A.D. The Íslendingabók records that early Norse visitors to southern Greenland found still-recognizable ruins and artifacts of "The Skrælings of the same type as those who inhabited Vínland," which must refer to the Dorset Paleoeskimo, but not to direct contact, apparently supporting the archaeological evidence indicating Dorset withdrawal to the north in this period (Gulløv 2004) and suggesting an empty adaptive niche ca. 950–1000 A.D. While much research is currently ongoing in Greenland and Arctic Canada, it is probably still fair to say that we do not yet fully understand the dynamics of the centuries-long Norse-Dorset contact period of ca. 1000–1200 A.D., but evidence is growing that this contact was probably of very different character from the Thule-Norse interactions after 1200 A.D. in Greenland (Gulløv 1997, 1999, 2000; Schledermann and McCullough 2003; Sutherland 2000). As in Iceland, there is at present no direct archaeological evidence for a Norse hunter's settlement predating the arrival of Eirik's farmers, but there may be some hints of their presence surviving in Eirik the Red's own saga.

Walrus are found throughout Greenlandic waters, but have historically concentrated in the Disko Bay area half way up the west coast where rich feeding grounds and multiple hauling-out locations [*uglit*] still produce some of the largest concentrations of walrus in the eastern Arctic. The distance from Iceland to the west coast of Greenland, and the prime hunting grounds of the Disko region, combined with the need to trap fur bearing animals in the wintertime required permanent bases in Greenland, and these were rapidly established (Figure 1). Both written sources and archaeology (Gad 1970; McGovern 1985a) confirm that Disko Bay was the area of the medieval Norse Norðrsetur [northern hunting grounds].

These attractions, plus the opportunities to pioneer a new wave of settlement and become leaders in a new land most probably provided the powerful motivation necessary for launching a major and hazardous colonization effort. In tenth century Iceland the initial fleet assembled by Eirik the Red (apparently 25 ocean-going ships), and subsequent fleets of ships and colonists must have represented a very significant capital investment. The timing was probably critical. Iceland had been colonized sufficiently early in the Viking Age, that its own potential for providing prestige trade items was effectively exhausted, yet Icelandic settlement was sufficiently well established to mount a substantial colonization effort and, above all, the European market for ivory and fur was buoyant and favorable in the late tenth and early eleventh centuries.

Arctic hunting certainly did not decline with the establishment of farming communities in the inner fjords of southwest Greenland. There are several lost poems describing hunting trips to the Norðrsetur, and surviving accounts record the number of weeks of travel required to reach the distant hunting grounds from the Western Settlement (modern Nuuk district) and the larger Eastern Settlement (modern Qaqortoq and Narsaq districts) further south. These long summer voyages deprived the farming communities to the south of vital adult labor and scarce boats for one of the busiest parts of the agricultural year, but they continued nevertheless throughout the history of Norse Greenland. Fragments of the dense maxillary bone surrounding the deep-rooted walrus tusks are concentrated on high status sites in both Western and Eastern Settlements (McGovern et al. 1996; Church et al. in press), but some maxillary chips are found in virtually every archaeofauna collection known from Norse Greenland, including those from small far inland sites (McGovern 1994; McGovern et al. 1996). Final extraction of the ivory and its preparation for export was thus a dispersed winter "cottage industry" on most farms and a major household chore on the larger magnate farms. Concentrations of walrus tusk processing debris actually increase through time in current stratified bone collections and there is certainly no evidence that the intensity of the hunt slackened in the later medieval period. Recent archaeological research by the SILA Greenland Research Centre of the National Museum of Denmark at the newly discovered trading center at Sandhavn near Kap Farvel in southern Greenland serves to underline the importance of trade and export in Norse Greenland (Gulløv 2004) and many authors have suggested that the huge storage buildings on the bishop's manor at Gardar played a role as warehouses for export (Gulløv 2004:242–243; McGovern 1985b; Nørlund 1930).

Walrus penis bones (bacula) are also regularly recovered from farm sites far from the Norðrsetur, and rows of complete walrus and narwhal skulls were interred inside the consecrated churchyard dike at the cathedral at Gardar (Krogh 1983: 163; McGovern 1985b). While walrus ivory itself is extremely rare in Norse Greenlandic artifact collections, small objects made from the peg-like post-canines were commonly used for buttons and craft work, including small walrus, polar bear, and sea bird figurines pierced for suspension (Fitzhugh and Ward, (eds.) 2000). Walrus hunting and the Norðrsetur voyages were thus socially, and perhaps even ritually, embedded in the society of Norse Greenland, and there is every indication that the Norse Greenlanders highly valued the hunt for reasons sometimes transcending coldly calculated economics.

With this hunting orientated perspective in mind, subsistence in Greenland could be seen as primarily the means to underpin an export economy, and not simply an end in its self. Previous paleoeconomic reconstructions viewing the Norðrsetur hunt as a curious adjunct to the main business of household subsistence (McGovern 1985) may have actually had the economic emphasis precisely backwards. If we view the Norðrsetur hunt as the original and continuing core reason for the existence of Norse Greenland, then the subsequent development of this export economy becomes a key issue.

Norse Greenlanders and Wider Developments in the North Atlantic Region

Changing Trade

In Scandinavia, the Norse traded furs from the Sami in the north and the Finns in the east, both to sell on the growing European market and to export to the Middle East by way of the great Russian rivers. The famous late ninth century A.D. account made by the North Norwegian chieftain Ohthere to King Alfred is still a key source concerning the acquisition and marketing of such Arctic prestige goods by Nordic traders in the early Viking age. The Icelandic and Greenlandic walrus ivory exports thus fall neatly into the pattern of early Viking low-bulk, high-value trade in prestige goods. After the 1240s A.D., Hansa merchants in collaboration with Novgorod and other Russian city states developed the fur trade from the Baltic region northwards into the White Sea; elephant ivory from Africa began to provide unbeatable competition to walrus ivory in European markets and, perhaps most importantly, religious art increasingly moved away from the use of ivory (Roesdahl 2005). Other developments could have eroded the trade position of the Greenlanders: the development of hemp ropes, for example, may have effectively replaced a market for cables made from walrus hide. Add increasing operational difficulties in Greenland (caused by colder, stormier weather and more sea ice) to a fundamental erosion of the Norse Greenlanders' economic position, then their situation could have become dire. In addition, the Black Death of 1347–1351 A.D. and subsequent plagues heavily depleted the population in Europe (Goltfried 1983), and in Norway the loss of 30 to 50 percent of the population led to an economic collapse; the value of silver dropped to roughly one-third of its previous value, relative to the price of land and food. Hence the value of ivory relative to stockfish must also have been subject to a significant drop.

The development and expansion of the trade in dried Atlantic cod around 1100 A.D. was to have widespread economic impacts throughout Europe, which probably did not work to the advantage of the Norse Greenlanders. Thanks to a comprehensive zooarchaeological synthesis carried out by James Barrett and colleagues (Barrett, Locker, and Roberts 2004a; 2004b) we now know that prior to a "Fish Event Horizon" (FEH) around 950–1050 A.D. virtually no marine fish bones appear on any inland site in Britain, but after the horizon they become common, as suggested by the historical record. In the Norse-occupied Northern and Western Isles, "fish middens" densely packed with fish bone showing evidence of preparation for export first become common ca 1050–1100 A.D. (Barrett 2000, Barrett, Locker, and Roberts 2004a, 2004b, Barrett, Nicholson, and Cerron-Carrasco 1997, Barrett 2003, 2005; Bond 1998). By the early 1100s A.D. the Norwegian crown and church had begun to fully organize the stock fish trade based on the rich winter fisheries of Lofoten and Vesterålen An earlier intra-Norse trade in dried marine fish predated the FEH in both Iceland and Faroes by at least a century (Brewington 2007; McGovern et al. 2006; Perdikaris and McGovern in press a and b). Early coastal settlements in North West Iceland may well have controlled local pre-FEH fish production and by 1250 A.D. the region was a major center in the production of dried fish for export and local consumption (Amundsen et al. 2005; Edvardsson et al. 2004; Edvardsson and McGovern 2005). After the FEH what was to prove a major and long-lasting engine for economic development increasingly connected Iceland and Norse Scotland to the rapidly expanding urban markets of Europe.

By the thirteenth century A.D. this trade in low-value, large-bulk consumption goods was offering an effective alternative to the prestige trade in ivory and fur. This development was symptomatic of the "commercial revolution" in Europe during the thirteenth century (Spufford 2006:12). In other words, alternative ways to generate trade goods and wealth were becoming available in Iceland and the draw may have been responsible for a critical hemorrhage of people from Greenland (Lynnerup 2003).

Thule Contact with Dorset and Norse

While nearly 300 years of Dorset-Norse contact in Greenland and the eastern arctic remains incompletely understood, it seems to have had fairly limited impacts on either population. Certainly neither the Norse nor the Dorset seem to have significantly expanded their settlement areas after the period of the Norse Landnám and the probable times of initial Norse-Dorset contact around 1000–1100 A.D. This was not the case when the Thule people expanded eastwards into Arctic Canada and Greenland, as they replaced both Dorset and Norse—culturally if not biologically—throughout the region before 1500 A.D. The timing and motivation for the Thule expansion is still an area of intense and productive research across the Arctic, but a growing consensus sees the Thule migration reaching northern Greenland around 1200 A.D.(Gulløv 2004; Schledermann and McCullough 2003). Robert McGhee (1984, 2003) has updated his earlier stress upon warm climate and intensive bowhead whale hunting, arguing that a major cause for the Thule people's long journey eastwards was, in fact, an effort to track down the source of the metal and other desirable trade goods that had been trickling westward over the previous centuries. Extensive recent archaeological and ethnographic research in the western Arctic has indicated cyclical patterns in episodes of intensified whaling associated with intensified warfare (e.g., Mason 1998). Thus, the Thule reaching Greenland in the thirteenth century A.D. may well have been far more experienced and skilled in low-intensity warfare than once believed, and so might have had combat skills superior to those of the Norse Greenlanders, who by 1200 A.D. were neither Viking warriors nor medieval men at arms, but peasant farmers. On the west coast of Greenland, Thule winter settlements spread rapidly southwards. Mathiassen's excavations at the unusually large and nucleated Thule settlement at Sermermiut in the Disko Bay region (Mathiassen 1958) produced extensive collections of Norse artifacts (church bell fragments, woolen cloth, substantial amounts of iron, and draughtsmen converted into tops—all types also recovered from later excavations in Inuit contexts in Greenland). As Sermermuit lies directly across the Norse sailing route to the Norðrsetur its many residents could have posed a serious threat to Norse hunting parties if hostilities broke out. In these circumstances, the smaller Inuit winter settlements which reached the outer fjords of Godthaabsfjord by ca. 1300 (Gulløv 1997, 1999) and occupied the seasonal sealing grounds of the Norse Western Settlement, could also have presented an additional potential threat to Norse seasonal subsistence sealing.

The Norse did not adopt Inuit ice hunting techniques and thus did not take many ringed seal (*Phoca hispida*) (McGovern 2000), but perhaps optimizing subsistence was not the key issue through the long decades of apparent success until the very last years of the settlement when a terminal crisis may have developed too quickly to permit any adaptive change. The economic perspective raises the possibility that an Inuit lifestyle might not have been chosen by the Norse in the thirteenth and fourteenth centuries because it was not needed, and the main contact issue may have been the potential disruption of the Norðrsetur connection and potential loss of Norse hunters and scarce boats during periods of conflict. As a result the key problems facing the Norse Greenlandic settlements could have been those of limited population, meeting labor requirements, and economic viability; even quite limited out migration driven by changing trade or sporadic casualties in low-intensity warfare could have had very serious consequences for long term viability.

Adaptation, Population, and the Possibility of a Rapid Final Crisis

While the Norse middens do not contain harpoons or the ringed seals usually taken with such gear, the Norse Greenlanders were certainly highly competent seal hunters who made use of nets and probably communal boat drives aimed at the millions of migrating harp (*Phoca groenlandicus*) and hooded seals (*Cystophora cristata*) arriving along the coast of West Greenland in spring. These hugely abundant migratory species were rare or absent in the rest of the Viking Age North Atlantic, and they presented a far richer resource, and one much less likely to be depleted by large scale exploitation, than the small resident harbor (*Phoca vitulina*) and grey seal (*Halichoerus gryphus*) colonies of Iceland or the British Isles. Norse archaeofauna in Greenland from the earliest phases have far more seal bones than appear in any of the other North Atlantic bone collections (Perdikaris and McGovern, in press c), and there is a general tendency for the relative percentages of seal bones to increase through time—topping 70% of the total in some smaller sites (McGovern et al. 1996, McGovern 2000). Isotopic evidence from human remains clearly indicates an increasing marine component in Norse diet in Greenland, suggesting that the seal hunt and other marine foraging played a progressively more vital role in subsistence (Arneborg, et al. 1999). Norse migratory seal hunting in Greenland was thus both highly productive and capable of expansion and intensification, and the Norse communal seal hunters were not only able to provision their communities without Inuit technology, but also capable of continuing to expand seal catches as long as labor and boats were available. The Norse seal hunters were thus no less competent than the Inuit, but they made far greater use of pooled communal labor and carefully scheduled targeting of seasonal concentrations of migratory seals rather than more individualistic year-round sealing with harpoons from kayak or ice edge. Communal seal harvesting, which probably involved most active adults in the community and distributed seal meat to every farm (even far inland), must have had a significant social dimension, hedged about with tradition and representing an annual expression of communal solidarity and cooperation (McGovern 1985a, 1991).

The Faroe Islands, where hunting of the pilot whale (*Globicephala melas*) has occurred for at least 500 years and probably since the Viking Age and has provided a significant part of the staple diet for centuries, may provide a social as well as economic model for communal seal hunting in Greenland (Bloch 1996; Guttesen 1996). In times of subsistence crisis, whales have provided a key resource to the Faroese, a point vividly demonstrated during the Second World War when in 1941 A.D. a record catch of 4,325 pilot whales provided a vital food supply (Guttesen 1996:90). The immediate and total mobilization of all active community members for a pilot whale drive remains a key element in modern Faroese society, enhanced rather than diminished by the availability of cell phones, email, and motorized transport, and totally undeterred by tourist sensibilities. The modern Faroese pilot whale drive is now primarily about community solidarity and the visible expression of core social values through collective action; but still, no dead whale goes uneaten.

The viability of Norse subsistence may thus be related to the degree of interdependence between farms and scale of the organization of labor resources required to maintain effective communal cooperation. A well-integrated network widening the geographical spread of producers and the range of food sources exploited could ensure effective buffering against shortage, but would require collaboration between households and probably between districts. The presence of seal and seabird bones at inland sites and caribou bones in coastal locations outwith their probable range all indicate economic integration well above the household level, suggesting pooling of labor at least seasonally (McGovern 1992, 1985b). Labor may have been in high demand for local farming activities as well. In Greenland, Norse flocks were nearly evenly split between sheep and goats throughout the settlement, and sheep were probably being managed largely for milk and not for significant surplus wool production (Mainland and Halstead 2005). In contrast, Icelandic archaeofauna show a shift in flocks to nearly all sheep by c. 1200 A.D., many of which seem to have been managed primarily for wool production (McGovern et al. 2006). Dairy herds require much more constant human contact and labor investment throughout the summer than flocks of infertile ewes and castrated rams or wethers, which were traditionally left to fend for themselves in the Icelandic highlands in summer. The extensively developed highland saeter and "dairy farms" documented in the Eastern Settlement in Greenland (Albrethsen and Keller 1986) probably reflect this more labor-intensive herding pattern aimed at maximizing provisions rather than wool production. In Greenland as in the rest of the North Atlantic, collection of winter fodder for stalled domestic animals was a labor-intensive process critical to stock survival (Amorosi et al. 1998). Deeper snow and longer winters in Greenland would increase the winter fodder demands relative to Iceland, and the rugged terrain and scattered patches of upland pasture in Greenland together with the rarity of extensive areas of highly productive wet meadow that were only partially compensated by extensive irrigation channels (Arneborg 2005; Keller 1983; Krogh 1974, 1982:103, 144) would tend to have reduced the labor efficiency of harvesters.

If the Norse settlements did function in large integrated units with significant interdependence, rather than a group of effectively independent semi-self sufficient units, the same community solidarity and collaboration evident in the Norðrsetur hunt and home processing of walrus tusks may well have also underwritten many components of the subsistence economy. Ironically the capacity of a well-integrated system to cope with variation may have meant that when a crisis sufficient to overwhelm the community did develop, it could have resulted in a catastrophic collapse.

The subsistence issue is closely linked to that of population, and population levels in Norse Greenland might have been significantly lower than previously assumed (Lynnerup 2000, 2003). Lynnerup's "low population" model, reaching a total of between 2,000 to 3,000 about 1300 A.D. is controversial, and significantly lower than the peak population range of 4,000 to 6,000 estimated by others (e.g., Berglund 1986; Keller 1986; McGovern 1979; Meldgaard 1965). Higher or lower population estimates and their changes through time have a number of key implications. On the one hand, if communal hunting activities make a major contribution to subsistence and the wild resources they tap into are effectively "unlimited," then higher population levels could be strongly beneficial and low or falling populations a problem. On the other hand, if pastoralism was critical, productive land limited, and land degradation through climate change and soil erosion significant, then lower or falling populations may have relieved or avoided a resource driven constraint. In this context, the intensive exploitation of small landholdings around isolated farms can be read in quite different ways if this was part of a rotating or shifting exploitation of the landscape (lower or more concentrated populations?), as opposed to a strategy demanded by a fully occupied landscape with no scope for movement (higher or more dispersed populations?). In other words intensive exploitation of resources at any one site—in the absence of regional perspectives based on multi-site/whole-landscape approaches—may be interpreted in quite different ways as either indications of "desperation" or "highly efficient maximum exploitation (perhaps followed by recovery?)."

Returning to the question of climate change, we now have two quite different ideas to consider. On the one hand, climate change could have been the principle challenge that drove the Norse Greenlanders to extinction. From this point of view maladaptation and a subsistence crisis were key problems. The area simply became too marginal for them to endure with their chosen lifestyle.

Alternatively, climate change might have been much less significant, influencing the timing, but not necessarily the ultimate fate of the settlements. Basic subsistence might have always been possible, but economic marginalization, and the presence of alternative options back in Iceland (or indeed elsewhere in Scandinavia – especially in post plague-ravaged Norway) may have fatally undermined the rationale and means for occupying Greenland, and drawn people away from the island. For these reasons population contraction might have reached the point where subsistence and survival did become impossible. At a critical level of sensitivity perhaps any number of events from extreme weather to disease or conflict could have provided the final push to collapse and extinction.

If the Norse did have a well-integrated and communal approach to living in Greenland, this may have contributed to a situation where a sudden crisis developed out of control and resulted in social collapse and the rapid extinction of the remaining population. The idea can be explored in a simple conceptual model of population and resources (Figure 3). The resources available to support the population are enhanced from their initial levels by a combination of introduced domesticated livestock, infrastructure (e.g., the creation of home fields, irrigation systems, and construction of shielings), interdependence, and the harnessing of materials from a wide area. A sudden population decline could interfere with the ability of the remaining population to continue an integrated approach to resource exploitation and exploitation of all the hitherto available resources due to shortages of labor (e.g., to continue sealing, hunting caribou, managing domestic livestock, collecting fodder, and so on). A cascading reduction of available resources could then outstrip population decline. Collapse may then result because of critical gaps between labor availability and key tasks, mismatches between supplies and demand, the losses of knowledge and skills, and perhaps most importantly of all a collapse of the social structures that provided stability and enabled the community to tackle collective tasks. This could have rapidly reinforced the initial population shock, forcing a continued decline below thresholds of viability, and initiated total collapse.

Taking this trade-orientated viewpoint, Norse Greenland would shift from being a case of maladaptation and an example of the impact of climate change, to being one of a series of examples of episodic European exploitation of the Polar regions where success or failure was primarily determined by economic circumstances. The ruins of Norse Greenland could therefore exist for fundamentally similar reasons to the traces left by

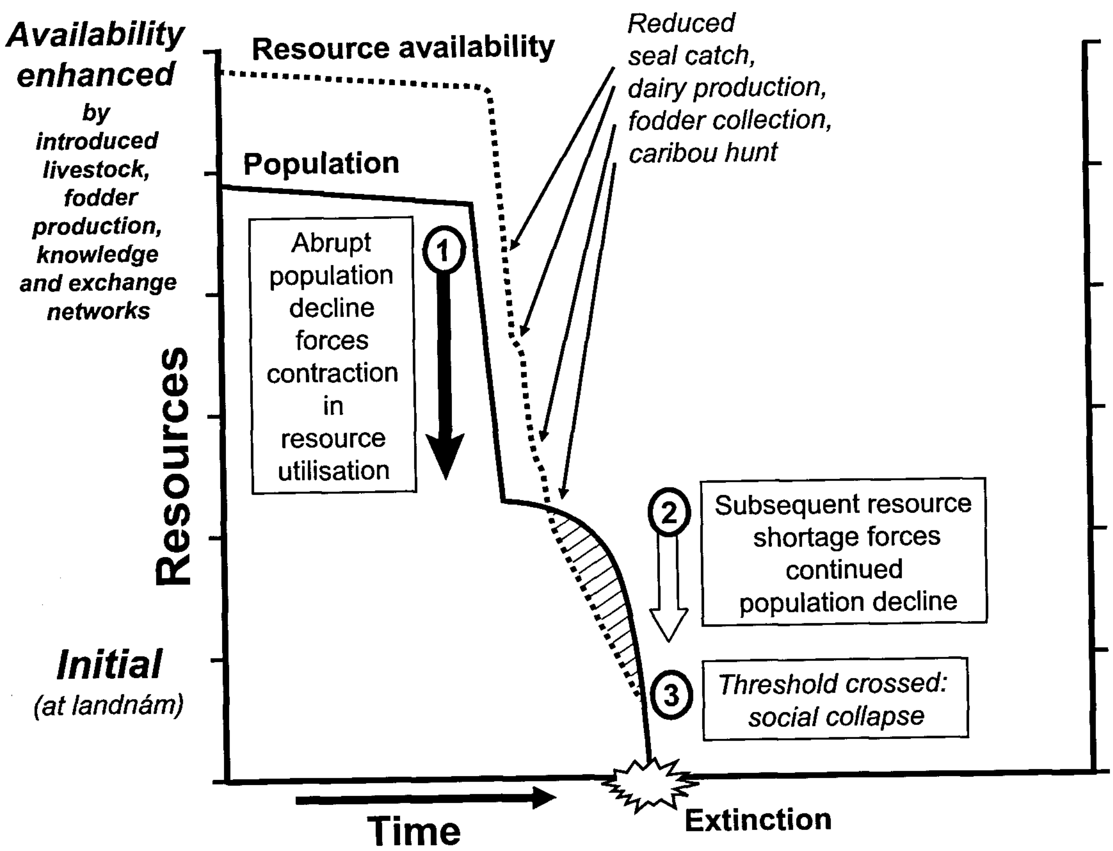

Figure 3. A "collapse model" for Greenland. See text for details.

whalers, sealers, and miners elsewhere in the Arctic and Antarctic (Sugden 1982), and it could be as misleading to read the record of Norse Greenland primarily in relation to periods of warmth or cold, calm or storm as it would be to do so with these other short-lived excursions into polar regions.

Is Climate Change Anything More Than the "Executor of the Unfit"?

It could be a mistake to rule out climate change as a cause of real and substantial negative impacts on otherwise viable settlement in the Atlantic Islands. Iceland in particular provides an important comparison to Greenland, because Icelandic settlement has also experienced major episodes of expansion and contraction and these have at least in part been associated with major climatic challenges and widespread environmental impacts, although, once again, the extent to which these impacts were solely the result of climate change is debated (Karlsson 2000). Even in medieval times Icelandic settlements supported many more people than Greenland (at least 10 and possibly more than 30 times as many people), and unlike Greenland, Iceland could not be argued to exist just as some extreme form of olden-day trading base camp. It was a place that people sought out, and where people stayed, because it was potentially a good place to live.

The idea of climate change having significant cultural impacts is encouraged by notable anecdotes of farm sites disappearing beneath advancing glaciers (Grove 1988). Environmental degradation has occurred on a large scale with extensive changes to vegetation cover (the reduction of woodlands to a fraction of their former extent) and widespread soil erosion (the loss of perhaps 20,000 km^2 of soil) (Arnalds et al. 1997; Dugmore et al. 2005; Thórarinsson 1961). Climate change has been argued to play a key role in this change (and so exert unwelcome pressures upon Icelandic society) because of a clear relationship between temperature and vegetation cover. In Iceland the boundaries of ecological zones (such as the upland limit of tree growth) are generally determined by temperature; if temperature changes then boundaries will change (Ólafsdóttir, Schlyter, and Haraldsson 2001). Temperatures decline and grass growth is affected. In addition, cold wet periods can critically affect other activities such as fodder collection, the chance of successfully over wintering livestock, and lambing, producing high neo-natal fatalities for sheep (Amorosi et al. 1997).

Despite these clear associations with climate, it is apparent from the environmental record that some environmental degradation, such as soil erosion, began very soon after settlement in the late ninth century, and developed even at times when climate change is not thought to be an issue (Dugmore et al. 2000, 2006; Ogilvie and McGovern 2000; Thórarinsson 1961). As a result we need to be able to disentangle the roles of climate change and nonclimatic factors in landscape degradation. One point of view, to put it crudely, is simply that people are very bad for the environment and human settlement and degradation always and inevitably go hand in hand. This observation is important for our interpretation of settlement decline in Greenland because, if true, it could strengthen the case for maladaptation and its potential role in promotion of crises. This *"ultra Malthusian"* view, that environmental degradation by the Norse in Iceland was simply and inevitably a result of human over exploitation cannot, however, offer a complete explanation, because we have evidence for environmentally aware and responsive practices that have managed impact, avoiding total catastrophe.

Environmental Interaction of the Norse in the Tenth through the Fifteenth Centuries A.D.

Woodland Decline in Iceland—An Ecological Catastrophe or a Managed Landscape Fit for Purpose?

In Iceland today, woodlands are but small remnants of the pre-historic forests and this can be viewed as a result of inappropriate land management (Eysteinsson and Blöndal 2003). Indeed there are many historical examples of conflict as a result of disputes over this declining resource, as through much of Icelandic history native woodland was the key source of charcoal, vital for the effective maintenance of tools and farm operations. Perhaps, however, a key point when considering the fate of Icelandic woodlands is that they have actually survived into the modern era (if in a much reduced form) —a better record than that of Rapi Nui/Easter Island (Flenley and Bahn 2003). In Iceland, measures were taken to conserve declining woodland resources when they had reached the point that further reductions could have been potentially catastrophic. In southern Iceland, for example, lowland woodlands were cleared rapidly (Hallsdóttir 1987). At the farm of Stóra Mörk (c. 30 km west of Þórsmörk), for example, tephra layers in peat sections show that woodlands in the area of the present home fields were cleared between 870 and 920 A.D., and probably within the first 30 years of settlement (Mairs et al. 2006) (Fig. 1). Up valley, charcoal production pits (also preserved in aggrading soil profiles containing

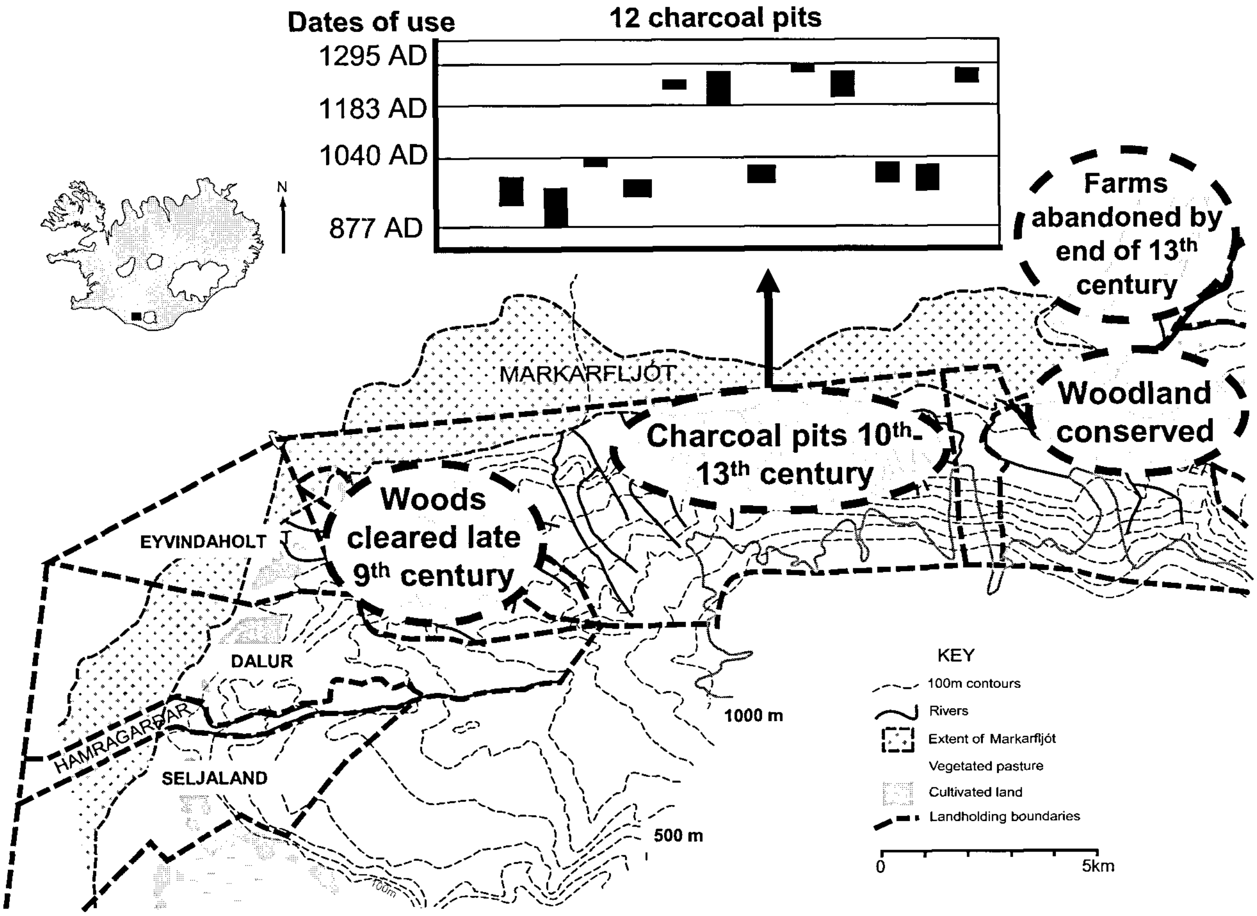

Figure 4. Woodland change in southern Iceland. By the end of the thirteenth century A.D. the progressive loss of woodland in Markarfljót valley had reached Þórsmörk; here farm sites were abandoned, and the surrounding woodlands survived through seven centuries to the present, while they continued to be used as a vital and major source of charcoal for farms in the region (Dugmore et al. 2006; Church et al. in press). This can be interpreted as an example of the medieval Norse successfully responding to a developing environmental issue, and has implications for how we view the Norse Greenlanders' responses to similar issues at similar times.

more tephra layers) record the use of birch wood (*Betula pubescens*) between 877–1295 A.D. (Dugmore et al. 2006; Church et al. in press) (Fig. 4). No production pits have been found in this area that post date the fourteenth century, and there is no birch woodland in the area today. At the inland margins of the valley isolated areas of woodland survive to this day in Þórsmörk, and this area was intensively managed for charcoal production through to early modern times. There is a pattern of progressive woodland destruction and continued survival in isolated areas close to the upland ecological margin in Iceland in general and in other southern valleys such as Þjórsádalur in particular (Fig. 1) The implication from the environmental record is that actions were taken to conserve resources before they were completely destroyed.

In Þórsmörk, where the woodlands survived, there lie the ruins of four farm sites known, on the basis of both the written record and artifact evidence from the sites themselves, to have been established early and abandoned before the fourteenth century (Tómasson 1996). Recent environmental work has shown that the occupation of these sites coincided with major localized episodes of soil erosion (Dugmore et al. 2006). After the Þórsmörk farm sites were abandoned, the affected areas began to regenerate and soils began to reform. Once again, precise dating control is given by the distribution of well-dated layers of volcanic ash. Abandonment of these farm sites, lying at the upland limit of settlement in the region, might be argued to be a consequence of the localized destruction of grazing lands associated with the first introduction of domesticated animals. Importantly, however, destruction was limited to upland grazing areas. Within sheltered valleys containing woodlands today, there is evidence that woodland survived throughout the period of occupation. One possibility is that farm abandonment, while related to the increasing loss of grazing land, could in fact have been driven by a more general communal need to conserve a diminishing supply of woodland. Once the woodlands had been destroyed down valley, people could have recognized the importance of conserving the surviving remnant in Þórsmörk. The farms (and presumably their associated livestock) were removed and the woodland, now under the control of lowland landowners and the church, survived (Dugmore et al. 2006).

A key point of this example is that even when exploitation of a resource and related environmental degradation appears ill-conceived (the near-total destruction of native woodland), successful corrective conservation measures were employed in at least some areas before the resource was totally lost. Significantly for the understanding of events in Greenland, and these actions were taking place in Iceland in the thirteenth century, showing that the Norse at this time were capable of responding to an environmental challenge in a constructive and ultimately semi sustainable manner.

Animal Conservation and Extinction

The ability to practice a sustainable exploitation of wild resources could have been key to effective subsistence in Norse Greenland. In the Faroe Islands (Fig. 1) a substantial pilot whale hunt has been sustained for at least five centuries, but exploitation takes place within the confines of the archipelago, harvesting an extensive pelagic population. The scales are such that it could have been impossible for an island-based kill to compromise the viability of the pilot whale population as a whole in the wider North Atlantic. Land based birds offer more sensitive examples because of their potential vulnerability. Around Lake Mývatn in Iceland (Fig. 1) harvesting of duck eggs is an important local farm activity, with some 10,000 eggs a year collected. New evidence shows that duck eggs were being exploited over 1,000 years ago, and although many different species of adult birds were being killed and eaten as well, zooarchaeological data indicate that waterfowl hunting was avoided, and the Ptarmigan (*Lagopus mutus*) was the focus of hunting efforts (McGovern et al. 2006). A thousand years after exploitation began duck populations still flourish (because some eggs are always left in the nests to hatch) and, significantly, ptarmigan still endure in the heath and uplands as well. Elsewhere in the Atlantic this view of sustainable Norse practices is reinforced: in the Faroe Islands, puffin (*Fratercula arctica*) make up a significant population of the early archaeofauna at the site of Sandur, showing that they were intensively exploited for food, but again populations still flourish on the islands (Church et al. 2005). The record is not, however, one of universal continuity and endurance as there are notable examples of both localized extinction (walrus colonies no longer occupy the coasts of Iceland) and acts of species extinction (the last Great Auk (*Pinguinus impennis*) was killed in 1844 A.D. on a small island of Eldey off the coast of Iceland) (Bárðarson 1986). The key point is, however, that there is empirical zooarchaeological evidence for practices that began in Viking Age Iceland, at the time Icelanders were colonizing Greenland that have proved sustainable over more than 1,000 years.

Grazing Management

The effective management of grazing is another key sign of adaptation. The notion of sustainability does occur in Norse records of medieval land management as contained in passages of the Old Icelandic law code, Grágás (Dennis, Foote, and Perkins 1993; Simpson et al. 2001). The code was replaced in the 1280s A.D. after the end of the Icelandic Commonwealth period, but offers key insights into the principles of early land management in Iceland, principles that could have been similar to those practiced in contemporary Norse Greenland. Grazing rights were owned, managed, and regulated. Stocking levels were determined by the stage at which livestock began to lose weight. If the animals became thinner throughout the year, then stocking levels were deemed to be too high. This is strong evidence that upland environmental degradation was not simply a result of over exploitation and a "*tragedy of the commons.*"

The Ability to Adapt

A consideration of case studies of Faroese and early Icelandic use of marine mammal, bird, woodland, and grazing resources argues for flexibility and innovation and significant degrees of sustainable management within landscapes fit for purpose. We have examples of how to determine sustainable practice (monitoring the weight of livestock), evidence of management tools (ownership and regulation of grazing, legal sanctions for malpractice), examples of sustainable exploitation (duck eggs and pilot whales), and examples of corrective measures taken to conserve declining resources (woodlands for charcoal production). But, in addition, we do have examples of overexploitation and extinction (the Icelandic walrus and Great Auk) and we have evidence of major environmental issues (extensive soil erosion) and a history marked by repeated examples of population decline and hardship. So why did people "get it wrong"?

Problems of Prediction

Possible explanations for why apparently good practices and proven abilities to adapt and respond effectively to new challenges have produced very mixed results, bringing us back to the question of climatic impacts, especially the consequences of the Little Ice Age climate changes (Grove 1988; Meeker and Mayewski 2002). As the climate record through the last two centuries of the Norse settlements in Greenland includes significant variability, it is difficult to fasten on any one particular episode of unfavorable weather as the critical event as these repeated frequently. Climate change could be most readily translated into effects that people responded to badly by changes that are substantial, unpredictable and repeated, as opposed to changes that are gradual and predictable. Whether "bad" becomes "catastrophic" depends on how human societies can cope, and this is a reflection of social attitudes and structure, economic and political systems, as well as demographic fundamentals such as the potential labor force. Although a sudden episode of bad weather in any one year may be difficult, a sequence of bad years could rapidly change hardship into crisis and then catastrophe, as the ability to buffer any negative impacts of change are exhausted. Extreme events capture the imagination, and it is easy to accept the argument that major, abrupt changes may be significant, but what about the lower order changes, gradual, but significant shifts in climate that erode prosperity and draw down both natural and social capital over a number of years?

Returning to the example of rangeland management, problems in Iceland may well have developed even though people understood environmental dynamics and had sound management mechanisms in place, because of climate changes that unpredictably affected the onset and length of the growing season. Although sufficient biomass could grow through the summer to support the livestock grazing on the hills, a delayed start to the growing season could have resulted in grazing before any growth began, compromising the stability of vegetation cover (Simpson et al. 2001).

The problem created by short phases of heightened impacts on vegetation could have been compounded by three other factors. First, minimal (if any) shepherding of livestock utilizing the rangelands, while economizing on labor demands and freeing people for other tasks (such as fishing or textile production), could have significantly increased potential vulnerability to climatic impacts. Without day-to-day management of livestock grazing (to utilize the best or most robust areas of vegetation, and reduce pressure on vulnerable, eroding areas) regeneration would be difficult to promote. Often in the Norse world, however, shepherding was children's work, and so may not have drawn the adult workforce away from other tasks.

Second, although monitoring the weight of livestock brought down off the hills in the autumn is an effective way to maximize yield, the practice is probably insensitive to the onset of accelerated environmental costs as it is probable that landscape degradation would begin before livestock weight reduction became apparent. As a result, landscape problems could develop before the animal monitoring mechanism highlighted the issue. In this case draw-down of natural capital could have been an immediate consequence of unforeseen (and unmanaged) changes. Archaeological surveys have revealed examples of water-management strategies, both to harness snow melting and for irrigation, but most of these measures were focused on the home-fields, leaving the rangeland more or less untouched. Boundary turf walls in the mountain pastures, established to control the pastures (Einarsson, Hansson, and Vésteinsson 2002) may sometimes have prevented, and some times (ironically) have accelerated water erosion.

Thirdly, the nature of soil erosion in Iceland has distinctive features that can effectively propagate initially limited impacts. Over most of the landscape vegetated at the time of Norse settlement soil cover occurred in the form of a deep (>50cm) sediment of aeolian origin with intercalated layers of volcanic ash (Dugmore et al. 2000; Thórarinsson 1961). In the south of Iceland, lowland pre-settlement soil covers were commonly several meters deep. Once trees have been removed, the root zone is effectively confined to upper layers of the soil, and does not extend down into the underlying substrait of coarse-grained sediments. Soil erosion develops by exploiting breeches in the vegetation cover that allow frost, wind, and rain to move sediment. Bare patches of exposed substrait develop, bordered by steep, eroding faces of soil that under-cut and eat into the surrounding vegetated areas. Soil erosion then proceeds as a loss of soil area. Once established, erosion is resistant to stabilization, as even low grazing intensities will tend to keep bare soil exposed on the eroding slopes, permitting the continued effective action of the elements. It is useful to think of soil erosion having two key stages: a *triggering event*, which results in the breeching of the vegetation cover (and is usually related to grazing), and a *propagation phase* which is driven by the intensity of frost action, rainfall, slope wash, and wind acting on exposed soil. A simple return to the conditions prevailing before the onset of soil erosion does not necessarily result in a cessation of erosion, and in that respect soil erosion is best regarded as a threshold change that has the form of a catastrophe cusp.

Although erosion could have been triggered by a mismatch between land use and the growing season, the initial damage may not have been immediately apparent, as the monitoring mechanisms seem to have focused on the livestock. But once erosion started, it would not necessarily stabilize even if climate conditions returned to their previous norm.

Misleading Memories

People may fail to appreciate that significant climate change has occurred, or be resistant to taking effective counter measures until too late, if their experiences of the past are an inappropriate guide to the future. A quantification of "unexpected" or "unpredictable" change may be usefully gained from measures of cumulative deviation. This measure is developed by determining the long term mean of a time series of data, say for example, annual temperature. For each year the deviation from the long term mean is calculated, then, starting at the oldest data point, Year 1 is presented as simply the deviation from the mean, Year 2 is defined by that year's deviation plus the deviation from Year 1, Year 3 is defined by that year's deviation plus the deviations from both Year 1 and Year 2, and so on. This is illustrated for different proxy records in Figures 5, 6, and 7. Cumulative analysis is not used to assess climate changes such as the North Atlantic Oscillation because the weather in any one year is independent of what happened in the previous year, but when considering people and the environment cumulative measures are most

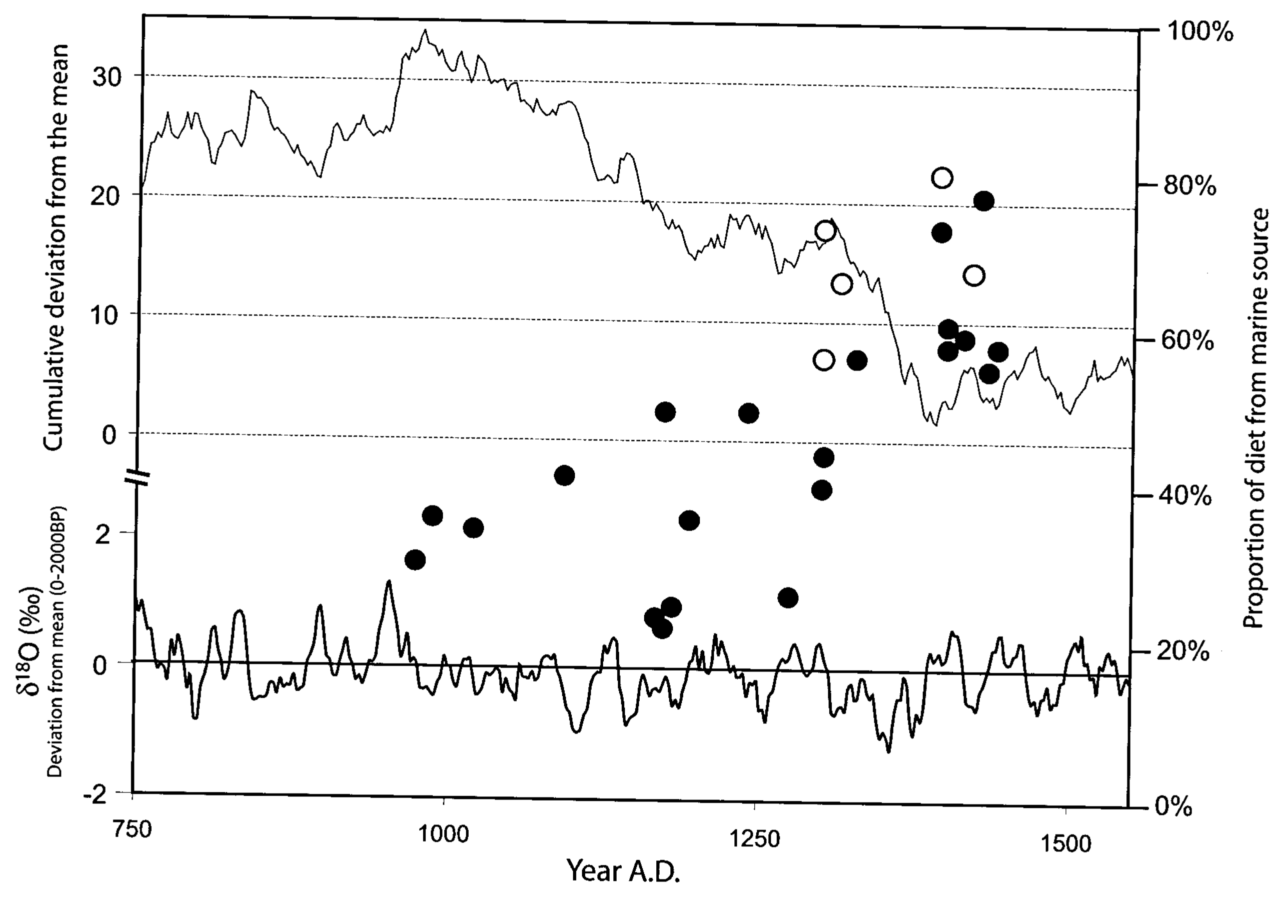

Figure 5. The δ ^{18}O time series from GISP2 (LHS scale), a proxy temperature record, shown against human isotopic data (RHS scale showing proportion of diet from marine sources) (Arneborg et al. 1999; Mayewski et al. 1993; Mayewski and White 2002; data from Greenland Ice Sheet Project 2. http://www.gisp2.sr.unh.edu/): Comparisons of δ ^{18}O time series for GISP2 and meteorological records for West Greenland for the period 1860 A.D. to the present demonstrate a statistical relationship between the δ ^{18}O time series and mean winter air temperatures across West Greenland (Barlow 2001; Dawson et al. 2003). The lower line is the 5 year running mean of deviations from the long term mean. The upper line is the same data presented as cumulative deviations (see text for explanation). The points represent isotopic data on Norse Greenlanders showing the proportion of marine food consumed. The change in the cumulative deviation —marking a shift to cooler condition—also marks the time of a distinct shift in the isotopic records of diet. Closed circles data from the Eastern Settlement, open circles data from the Western Settlement.

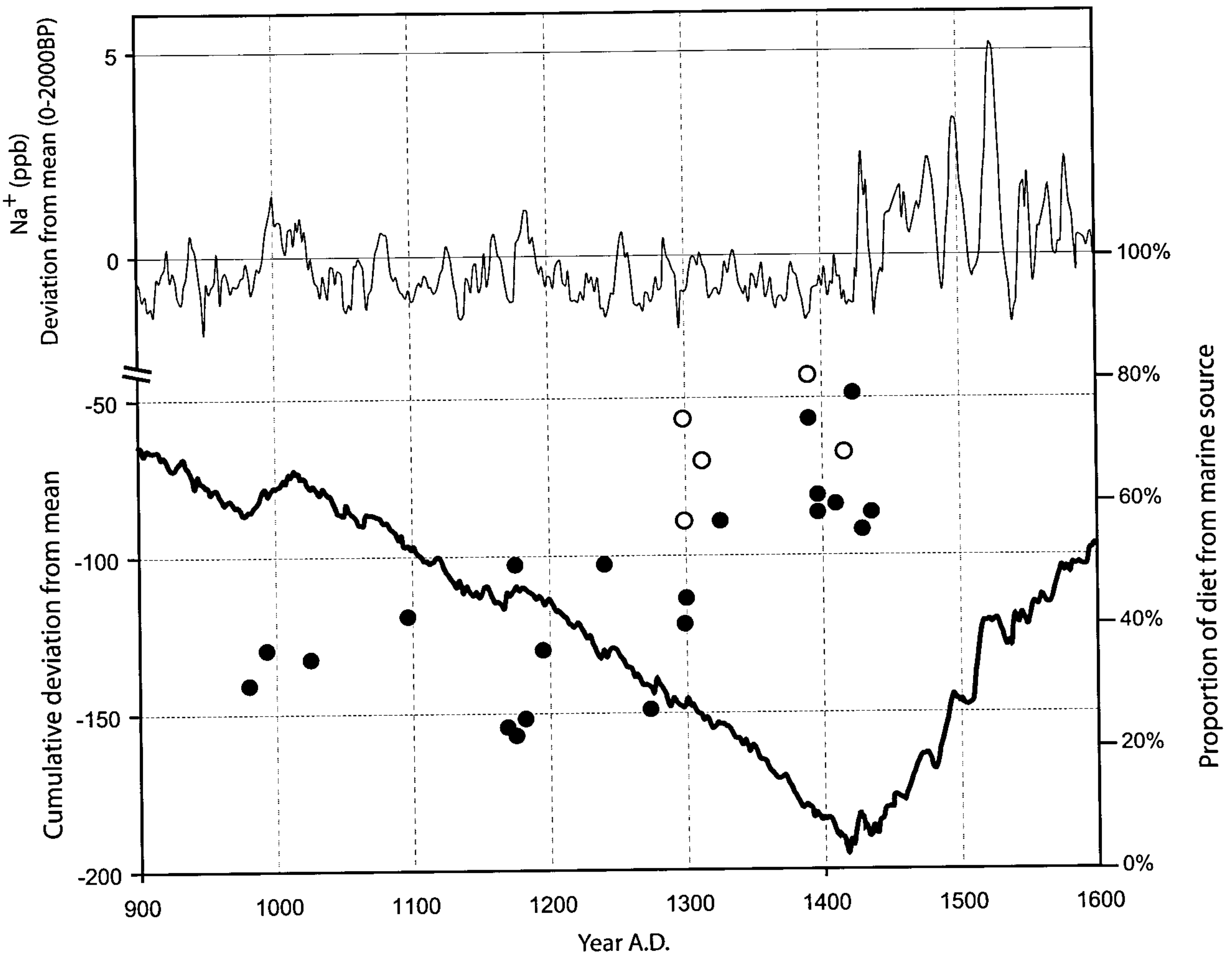

Figure 6. The Na+ concentration (sea salt) time series, a proxy record of storminess, from GISP2, shown against human isotopic data —lower RHS scale showing proportion of diet from marine sources (Arneborg et al. 1999; Meeker and Mayewski 2002; data from Greenland Ice Sheet Project 2. http://www.gisp2.sr.unh.edu/): The Na+ in the Greenland icecap derives principally from sea salt in the North Atlantic (Meeker and Mayewski 2002), so temporal variations in sea salt concentrations in the GISP2 record represent a proxy record for winter storminess in the North Atlantic. The upper line (top LHS scale) is the 5 year running mean of deviations from the long term mean. The lower line (LHS scale) is the same data presented as cumulative deviations (see text for explanation). Storminess is an indicator of regional circulation change in the North Atlantic, and perhaps unsurprisingly this regional measure of change does not show a strong correlation with evidence of dietary changes in Greenland but the most significant shift occurs within a short time of the final extinction of the Norse settlement. Closed circles data from the Eastern Settlement, open circles data from the Western Settlement.

instructive. For example, bad weather one year does have a continuing effect through its impact on vegetation; rain and wind year after year have cumulative effects on the development of soil erosion. Crucially, the measure of cumulative deviation clearly shows when trajectories of change alter. This is important not only for the environment, but also for people's perception of it. Our views of what is likely to happen next year are based on knowledge accumulated over previous years. Today, just as in the past, we use experiences and memory to anticipate what will happen next. Inappropriate actions may be taken most often when memories mislead; knowing when it is the time to change is perhaps the most obvious statement of how to deal with climate change, but perhaps the most difficult to resolve. How long is a new situation going to last? Do we just continue in the ways we always have, or do we take difficult decisions to alter what we do? Trying to manage a subsistence economy in a world of changing climates is a game where the player is blindfolded, since there is no way of knowing what the future has in store. Still, decisions have to be made. In a historical perspective, some of them will inevitably prove to be wrong.

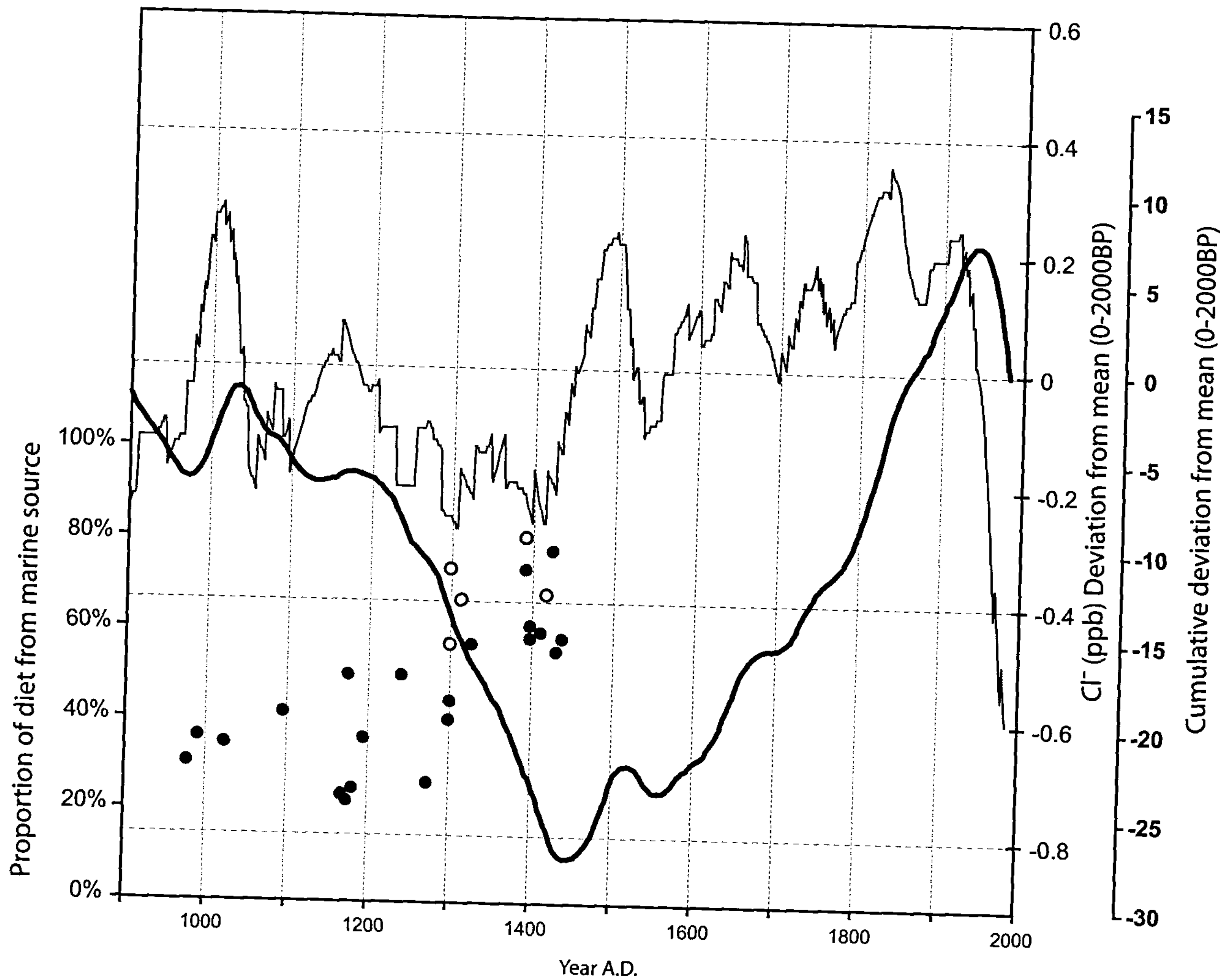

Figure 7. The proxy record of sea ice from GISP2 –RHS scales, bold figures cumulative scale (Dugmore et al. 2007; Mayewski et al. 1993) shown against human isotopic data, RHS scale showing proportion of diet from marine sources (Arneborg et al. 1999): The upper line is the 5 year running mean of deviations from the long term mean (data from Greenland Ice Sheet Project 2. http://www.gisp2.sr.unh.edu/). The lower line is the same data presented as cumulative deviations (see text for explanation). The most significant shift of the cumulative measure (most pronounced change in over 400 years, when past experience of anticyclonic conditions/sea ice extent were becoming the poorest indicator of future trajectories of change) occurs within a short time of the final extinction of the Norse settlement. Closed circles data from the Eastern Settlement, open circles data from the Western Settlement.

The extent of sea ice from GISP2 Cl⁻ excess timeseries: GISP2 ice core chemistry has been used to derive an estimate of past changes in sea ice extent around Greenland using the chloride (Cl^-) time series (both chloride excess and Cl^-/Na^+). Mayewski et al. (1993). Sea ice in the Greenland Sea is most extensive during April and May and the expansion of sea ice is associated with regionally increased surface air pressure. As a result changes in sea ice extent have been inferred from the non-sea salt Cl^- record as it is thought to reflect anticyclonic activity. Caution is needed in the interpretation of the chloride (Cl^-) time series, as sea ice expansion over the Greenland Sea can coincide with sea ice contraction in the Davis Strait and along the West Greenland coast and vica versa. Between 1270 A.D. and the twentieth century A.D. the pattern of the GISP2 Cl^- excess timeseries is broadly in agreement with historical reconstructions (e.g. Ogilvie, 1984, 1992), with a period of reduced sea ice cover between ca. 1050–1420 A.D. followed by a marked increase in sea ice extent that culminated during the late nineteenth century A.D. (Mayewski et al. 1993).

Isotopic data on the diet of Norse Greenlanders (Arneborg et al. 1999) has been plotted on the same graphs as temperature proxy data (Fig. 5), storminess data (Fig. 6) and sea ice proxy data (Fig. 7). Although the five-year running mean of temperature deviation shows little correspondence to the isotopic record, the biggest shift in the cumulative record coincides with a decisive shift in diet. This suggests first that, cumulative measures could be the best guide to the *type* of climate change that has the most significance for people and, second, that the Norse in Greenland did respond to this change with a shift in diet. The storminess record in Figure 6 shows what could have been a trigger for the end of the Norse settlement. The notable change in storminess in 1425 A.D. comes after the last recorded contact with the settlers. A similar relationship is suggested by the sea ice proxy (Fig. 7). In Greenland, and Iceland the mid fifteenth century A.D. was a time when past experience became an increasingly inappropriate guide to the future, and this increasing uncertainty about the future, in combination with the economic changes that had made the colonies increasingly marginal, might have signaled the end of the Norse settlements. No one knows exactly how long the last Norse Greenlanders survived. It is possible, however, that towards the end the social order may have broken down, and with it the communal efforts necessary for survival, resulting in a total collapse of the society. If so, final extinction may have come about very quickly.

Conclusions

Studies of past environments offer valuable insights into the relationships between people and climate change, and offer instructive examples of previous outcomes. As many alternative ideas come into play about the impact of climate change, the ways in which people respond to the challenges these changes pose, and the significance of coincident but wholly unrelated cultural changes, it is important to have rich, multi-layered data sets that include a wide range of environmental and cultural records. High resolution, seasonal, annual, and sub-decadal chronologies are essential, as are many different scales of enquiry. The human dimension needs to be evaluated on seasonal timescales, and spatial resolutions extending from individual settlement sites and land holdings, to groups of settlements in regional landscapes, and trade and socio-political relationships across continental scales.

Crucial distinctions have to be made between climate effects on subsistence and cash economies. Where subsistence is based on a wide range of resources (such as marine and terrestrial food supplies) this broad base may reduce one sort of vulnerability, because people exploit a range of plants and animals that could have wider or different sensitivities to climatic change than those who focus on a small area or specific parts of an ecosystem. Broad-based strategies of exploitation may, however, promote another sort of vulnerability by limiting labor availability for any one particular activity and so lessening its efficiency or return. Commercial opportunities can connect communities across wide areas, but in doing so they may also create increased potential for disruption as a result of climate change or, indeed, also for demographic or ecological changes in remote markets. This can happen because there is a greater chance that climate change may affect one part of the interconnection system, and so have cascading effects outside the areas actually affected by the changing weather.

Questions of scale are crucial. We can, for example, see how the fate of farms at the upland limits of settlement may have been affected by changes in the lowlands, so that despite localized environmental degradation (soil erosion), the key environmental change that determined abandonment was most probably degradation elsewhere (loss of woodland) and the needs that arose from that (conservation of surviving woodland at the upland margin). Likewise, but on a much larger scale, commercial changes in Europe could have been a key driver in creating sensitivities to climate change on the other side of the Atlantic in Norse Greenland. We conclude that shifting market conditions very far from Norse Greenland may have contributed to its economic marginalization, through the opening of the Mediterranean trade routes and the re-introduction of elephant ivory on the European market.

Asymmetric thresholds or catastrophe cusps may be crossed even in the presence of "sustainable" and responsive management strategies where changes are unpredictable and environmental impacts are not immediately significant or apparent. Cumulative measures of change are good analytical tools because they help focus attention on the implications for both cultural and environmental "memories" when the past is no longer an effective guide to the future.

One widely held view is that the impact of climate change, the failure of their pastoral subsistence base, and an inability to adapt were key factors in the end of Norse settlement in Greenland (Fig. 2). Alternatively, as we argue here, unfavorable economic changes and falling populations might actually have been the key factors in increasing the settlements' vulnerability to extinction (Fig. 8). Through much of the settlements' history the subsistence base of Norse Greenlanders could have been robustly based on hunting. Ultimately, however, critical numbers of people were

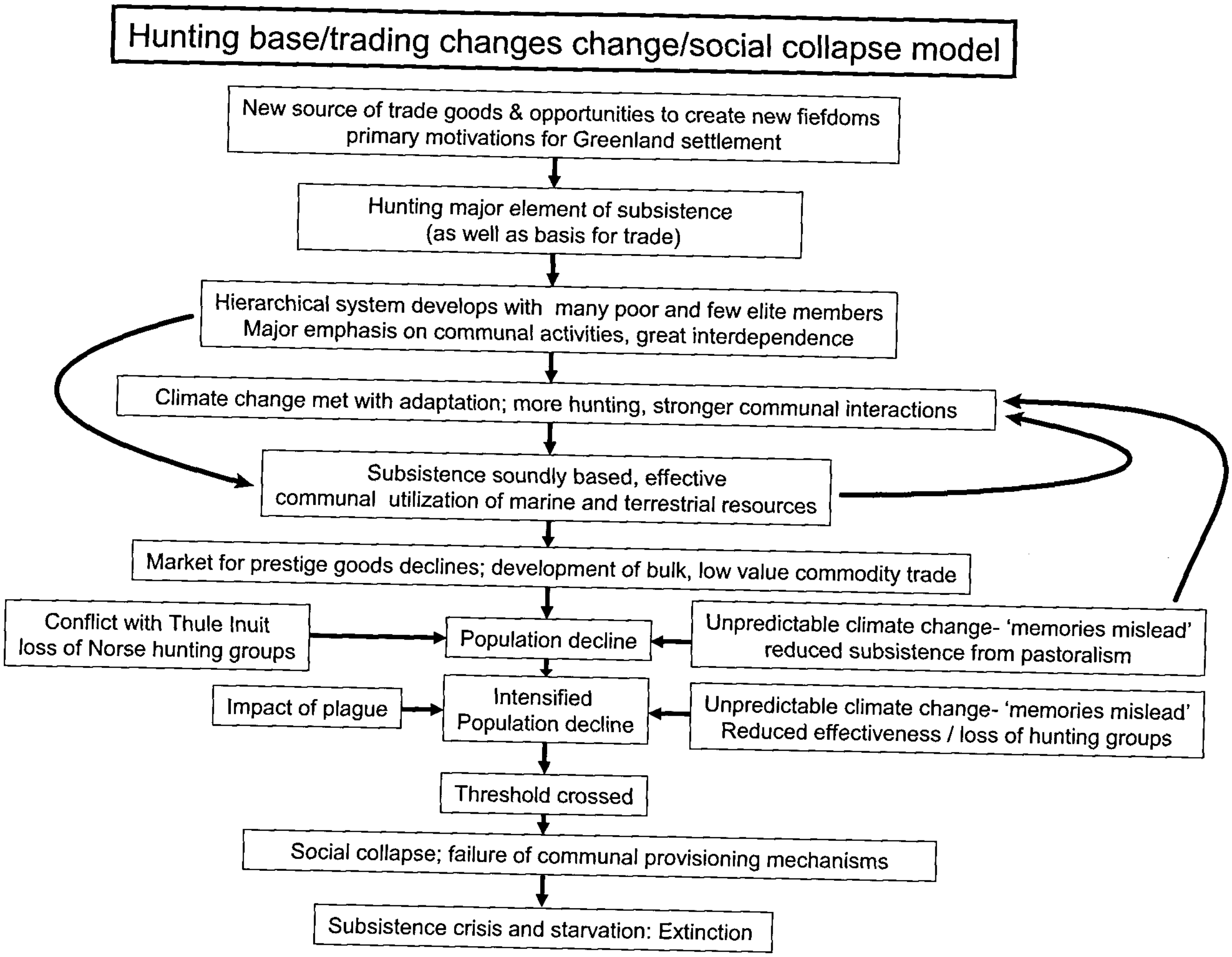

Figure 8. A conceptual model of Norse Greenland settlement highlighting the key roles of hunting, trade and social collapse.

necessary to maintain this way of life. Against a background of economic marginalization and population decline, we conclude that cumulative changes in climate and their relation to differing cultural and environmental "memories," combined with a cascading collapse of an integrated interdependent settlement system as a result of depopulation could have been the key factors in triggering the end of Norse Greenland.

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Endnote

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