CLIMATE, CORRELATION, AND CAUSATION IN NORSE GREENLAND

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This paper is dedicated to the memory of the late Dr. Richard Jordan, a good friend and fellow Greenland-farer whose acerbic comments on this and other papers will be sorely missed.

Abstract. Since the early 1960s, archaeologists working in the North have given the collection of paleoecological data an increasingly high priority, and have regularly relied upon paleoclimatic reconstructions for both the description of ancient resource base and the explanation of changing prehistoric population size, settlement patterns, and technology. Recently, senior northern scholars identified with climatic explanations have modified or rejected earlier conclusions (Fitzhugh and Lamb 1985; McGhee 1981), now stressing the role of nonclimatic variables. The experience of economic historians interested in climate impact further suggests the need for a cautious and self-conscious approach by archaeologists. This paper examines the case of the extinction of Norse Greenland in light of these perspectives.

Correlation and Explanation: Some Problems

The collapse and extinction of the Scandinavian colony of West Greenland has long been taken as a textbook example of the impact of climatic change on human society. Even before the evidence provided by modern climatology and the remarkable accomplishments of the Greenland Ice Sheet Project, scholars investigating this lost colony were generally convinced that cooling climate must have played a determining role in the death of Norse Greenland (Bruun 1918, Nansen 1911, Nørlund 1924, 1936). While early positions on the role of climate as executioner differ, they can be fairly summarized by the statement: "it got cold and they died."

Variations on this statement have been seen in other contexts in other parts of the Arctic, as well as in warmer regions (for an excellent critical review see McGhee 1981), often providing both a neat final solution to knotty problems of archaeological explanation and a fine justification for the collection of all those animal bones, sediment samples, pollen cores, and macrofloral specimens now routinely brought back from the field. As the precision and resolution of an ever-expanding battery of paleoclimatic indicators provide a progressively more realistic view of at least the nearer past, and as our contacts with like-minded natural scientists also expand, there is a natural tendency to use the harder paleoclimatic data sets to prop up our own wobblier descriptions of ancient societies.

As many have noted, description has a recurrent tendency to become explanation in the consciousness of the unwary. This process, plus the sheer amount of work involved in subsistence reconstruction, often leads us to feel that by the time we have put together a model of a settlement/subsistence system and set it beside a current paleoclimatic model our explanatory duties are just about complete, and if we can correlate some sort of

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archaeologically visible cultural shift with a period of climatic change our description can magically become explanation. Any number of prehistorians' studies have indeed stopped here, with concluding statements about culture change that boil down to "it got cold/hot/dry/wet and they died/floresced/migrated/intensified."

For decades, archaeologists working on historic sites have attempted to justify their grants by noting the potential role of later periods as a testing ground for concepts and methods popular with prehistorians. The richness and suspected precision of historic data sets are thus supposed to provide both illustrative set pieces and a sort of check on the work of colleagues dealing with more interesting or significant, but unfortunately less well documented cases. If investigation of the medieval-early modern period in the North Atlantic can play such an advisory role, then perhaps some cautionary signals should be hoisted regarding the efficacy of climatic correlation as explanation.

Climate and History Research

One major source of clear and rigorous thinking on the topic of climatic impact in historic times is the growing number of economic historians interested in the ecology of medieval/early modern agriculture in Europe. Often highly aware of advances in environmental science, this community has been much more receptive to climatic-change arguments than was an older generation scarred by Huntingtonian excesses (Huntington 1917). The documentation of significant shifts in mean temperatures between the "Little Climatic Optimum" or the "Early Medieval Warm Period" and the "Little Ice Age" or "Late Medieval Cold Period" by Brooks (1949) and Le Roy Ladurie (1972) and more memorably by H. H. Lamb (1977) and Bryson and Murray (1977) has resulted in a host of well-structured investigations of probable historical impacts throughout Europe and parts of North America. A recent series of edited volumes dealing with climate and history (Wigley et al. 1981; Smith and Parry 1981; Rotberg and Rabb 1980; Parry 1985, cf. Bigelow 1991) conveniently provide a survey of results.

If it is possible to distill a unified message from these varied conference volumes, it is that unambiguous cases of climatic impact are not easy to demonstrate in the historical record, and that arguments based on simple correlation are unconvincing. An extremely thorough and heavily quantitative study by de Vries (1980) of transport data; grain, butter, and fuel prices; burial statistics; and weather data for seventeenth to nineteenth century Holland concluded that variations in weather, even in the midst of the Little Ice Age, seemed to have little if any discernible impact in this particularly well documented case. A study of late eighteenth century Brittany by Sutherland (1981) likewise stressed the success of social buffering in smoothing medium-term climatic stresses. Comments by de Vries on the often referenced studies by Post (1977) and Pfister (1975, 1981) and Post's (1980: 721) rejoinder are all well worth consulting.

These negative or mixed results of climate-impact investigation in the world's most intensively studied historical region have led to some very cautious statements by historians and geographers still deeply committed to environmental history and climate study:

> . . . I am so far from regarding climatic change as of supreme importance to agricultural change that I consider it altogether subordinate to other factors [in particular to social and economic factors for change (Parry 1978)] and I thus hope that I shall not be taxed with embracing a notion which I look upon not merely as false, but as preposterous and absurd (Martin Parry 1981:16).

> . . . we conclude that the complex interrelationships between various parts of society make the detection of climatic impact extremely difficult, while in many historical situations climatic factors may be dismissed as of negligible importance (Wigley et al. 1981:3).

However, the very mercantile activities which provide so much of the rich documentary record for Holland, France, and England during these centuries may be themselves a symptom of what Bowden et al. (1981) describe as a "shedding" mechanism, whereby core states under stress shed the cost of climatic impact onto distant peripheries. The relatively developed nature of these core polities of the Wallersteinian World System (Wallerstein 1974) certainly provided Dutch burghers ready access to North Atlantic cod, Baltic grain, and tropical spices and beef by the local worst of the Little Ice Age around 1690. So if we see no clear climatic impact in these temperate zone centers of political and economic development, perhaps this is due to complex economic webs touching many distant markets. It might thus seem more productive to look at smaller, simpler societies closer to the climatic and social margins.

Northern Cases

If we turn to the Arctic and Subarctic, and particularly to the Eastern Arctic-North Atlantic region, there is no shortage of studies documenting the constraining effects of a cold and changeable climate on marine and terrestrial ecosystems exploited by local humans. Correlation of climatic change and culture change is commonplace in the literature, and has been used to explain changes in house form (Pedersen 1974; Schledermann 1976), local settlement expansion and contraction (Thorarinsson 1956, 1961; Parry 1978), and large scale movements of cultures and peoples (McGhee 1969/70, 1972;

Dekin 1972; Fitzhugh 1972; Stanford 1976; McGovern 1980/81).

There can be no question that relatively minor shifts in northern hemisphere temperatures can have marked impact in these latitudes, and few would imagine that phenomena like the presence or absence of summer pack ice would pass unnoticed by ancient residents. However, even in this region there has been a definite shift away from simple climatic correlation explanations in recent years. In part, this reorientation has sprung from the archaeological documentation of the range of adaptive strategies actually practiced in this supposedly restrictive zone. In part it is based upon growing sophistication in the use and interpretation of available climatic indicators. In the early 1970s it was less widely recognized that a paleoenvironmental indicator whose finest scale of resolution may be measured in centuries tells us little directly about human adaptive strategies played out on a scale of decades. As in other regions (cf. Gunn and Crumley 1986), far more attention is now being paid to matching of temporal and geographic scales.

As in climate history, there has also been a growing dissatisfaction in the North American Arctic with the notion of correlation as explanation, significantly felt most strongly by some of the very scholars whose early work most directly linked environmental and cultural change. Both McGhee (1981) and even more explicitly Fitzhugh (Fitzhugh and Lamb 1985) have questioned the deterministic assumptions of early models:

> These relations merely enhanced the possibility for culturally induced change across a very broad ecological and cultural frontier. As we learn more about the archaeology of Labrador, it appears that social and economic factors must be given a larger role in interpretations of cultural and territorial change (Fitzhugh and Lamb 1985:367).

In the North Atlantic, critics also have attacked early models which saw human settlement as a wholly dependent variable dominated by an admittedly overbearing climate. In Iceland, recent research has shown that the documentary data bases underlying sea-ice models like Koch's (1945) often-cited study are wholly unsound (Bell and Ogilvie 1978; Ogilvie 1981b). At the same time, the Icelandic scholar Gisli Gunnarson has strongly attacked both the theoretical and methodological underpinnings of climate history as applied to the Icelandic case (Gunnarson 1980). Astrid Ogilvie takes a more hopeful view of long-range possibilities—if correlation as explanation can be abandoned and a far more critical and rigorous approach to the historical sources adopted (Ogilvie 1981a, 1985, 1991; see also Durrenburger and Palsson 1989; Bigelow 1984, 1989, 1991; Sveinbjarnardottir et al. 1981, 1982, 1983).

Thus, the news from both the well-documented core and the northern peripheries is not particularly favorable to the notion that one can reliably predict human response from a knowledge of climatic variables alone, or that arguments from simple correlation can explain any such reaction, in prehistoric or in recent contexts. Thus statements like "it got cold and they died" are just not very useful, even if literally true.

Approaches to Linkage

Since it still seems instinctively reasonable that climate change and culture change *must* be connected somehow, many scholars in both climate history and northern archaeology have been searching for more rigorous ways of establishing linkage between climatic event and human economy.

The geographer Martin Parry has long championed a "retrodictive strategy" which involves the analysis of:

(1) the relationship between time, scale, and causality in climate-farming interactions;

(2) analogous crop-climate processes in the present;

(3) the relationship between weather variability and farming decisions; and

(4) changes in agro-climate (Parry 1981:6).

His work on farm abandonment in the Lammermuir region of the Scottish borders (esp. Parry and Carter 1985) provides an excellent example of the way in which modern crop tolerance data and documented climatic change on a yearly to decadal scale can be mapped onto a specific local topography, where predictions of chronic crop failure and eventual farm abandonment can be tested through rent records and field survey. In effect, this approach calls for the creation of a model of expectation based on current weather and resource data, allowing the researcher to "retrodict" periods and specific locations likely to experience hard times under certain clearly-specified situations. With such well-defined expectations of what would be likely to impact whom where and to what degree, we are certainly in a far better position to take a harder and more productive look at correlations between climatic and cultural change.

However, such models of expectation are no end in themselves, and they gain power and respectability only through regular contact with well-developed case studies supported by multiple, logically independent data sets. While case studies are not a substitute for general theory (Gunn and Crumley 1986), they are a vital necessity if debate on climate impact and social response is to progress beyond vague generalization. More information on climate response is desperately needed from a range of areas and periods, as we now are far from certain when and if small, isolated societies are more vulnerable to adverse impact than large and complex ones. This would appear to involve just the sort of conjunctive, environmental archaeology popularized in the 1960s–1970s, combined with the currently more fashionable concern for boundaries, long-range interactions, and politics.

The Case of Norse Greenland

For the past ten years, our team has been working on the problem of the Scandinavian colonization of the North Atlantic, with a special focus on Norse Greenland. This work has followed in the footsteps of a number of Scandinavian scholars, drawing on Greenlandic archaeological work dating to the end of the last century (Bruun 1896, 1917, 1918; Degerbøl 1929, 1934, 1936, 1941, 1943; Nørlund 1924, 1930, 1936; Nørlund and Stenberger 1934; Roussell 1936, 1941) and coordinating with many modern workers (Albrethsen 1982; Albrethsen and Keller 1986; Andreasen 1980, 1981, 1982; Christensen 1991; Halldorsson 1978; Olsen 1982; Gad 1982; Keller 1991, n.d.; Meldgaard 1977, 1982; E. L. Andersen 1982; Fredskild 1973, 1982; Stoklund 1982; Vebaek 1956, 1958, 1962, 1964, 1965, 1982, 1991; Schledermann 1982; Gulløv 1982; Weidick 1982; Hatting 1982; J. Andersen 1982; Krogh 1982a, 1982b; Berglund 1973, 1982, 1986; Møhl 1982; Sørensen 1982; Ostergaard 1982; Kleivan 1982; Jansen 1972; Buckland, Sveinbjarnardottir et al. 1983; McGhee and Einarsson 1983; McGhee 1984).

This research has provided us with a reasonably complete pattern of Norse sites, a number of useful zooarchaeological collections, and what little documentary evidence we are ever likely to have from the lost colony. This material has been discussed at length elsewhere (McGovern 1981, 1985a, 1985b, 1990, n.d.; McGovern and Jordan 1982; McGovern and Bigelow 1984; McGovern, Buckland, et al. 1983), and will be swiftly summarized here before we approach the topic of climatic impact.

Settlement/Subsistence Patterns

Most of Greenland is barren rock and ice. What green spots there are can be found at the heads of a few of the deep fjords of the southwest, and these ecological pockets are the only parts of the great island suitable for imported European domestic animals. If European settlers were to maintain the general pattern of North Atlantic herding/farming, they would have to be permanently limited to these few regions.

Within the pockets, there is great variation in vegetation, with some patches which are quite lush. These pastures were claimed by Eirik the Red and the other *Landnamsmen* (pioneer settlers: chieftains). Outside these most favored steadings, things get grimmer rapidly, and the poorer farms' pastures are poor indeed. Nevertheless, our fairly complete survey data and a few radiocarbon dates indicate that even the most marginal sites in the inner fjord pockets were occupied, probably within a generation of *Landnam*, or first settlement (Keller n.d.; McGovern n.d.).

The limited pastures of the inner fjords were probably never enough for a fully Icelandic-style agriculture, so the Norse also exploited a range of seals and the local caribou. Available faunal evidence (summarized in McGovern 1985b) and recent survey work (McGovern and Jordan 1981, 1982; Christensen 1991) indicate that both the spring harp sealing and the autumn caribou hunts were highly communal in character, involving drives, caches, and fairly extensive interfarm exchange. The spring sealing must have been particularly critical, providing a supply of meat and fat sorely needed after the long winter, when stored meat and dairy produce must have regularly run short.

In addition to subsistence economy, the Norse collected a cash crop—walrus ivory and hide. This *Nordrsetur* hunt (discussed more fully in McGovern 1985a) required a long and hazardous trip far north of the Norse settlement areas, and probably contributed little directly to subsistence. We do find bits of walrus skull from around the tusk root on the home farms (especially the larger farms), and a few ivory chips left from tusk extraction, but the tusks themselves all went to Europe in exchange for imported items, mainly iron and wood. Distant as it was from European markets, the Norse colony was a part of interregional trade networks.

Social Hierarchy

The unequal nature of West Greenland's patchy vegetation would tend to make some farms persistently more productive and more resilient in the face of extreme weather conditions than others. We would have reason to suspect some inequality in Norse society on ecological grounds even if there were no other evidence for social hierarchy.

However, we do have abundant documentary evidence for clearly defined ranking at first settlement, and if events followed the better-documented Icelandic case, the century and a half following *Landnam* would have seen plenty of exploitation of paupers, widows, and orphans, subversion of levelling mechanisms, voiding of chiefly social contracts, and escalating warfare as ambitious chieftains sorted things out in a fully-settled environment with little potential for further colonization (Sveinsson 1953). In Iceland at least, more and more people got deeper and deeper in debt to fewer and fewer great families. Households slipping from freeholding to tenant status also lost the right to participate in the local or regional assemblies, and

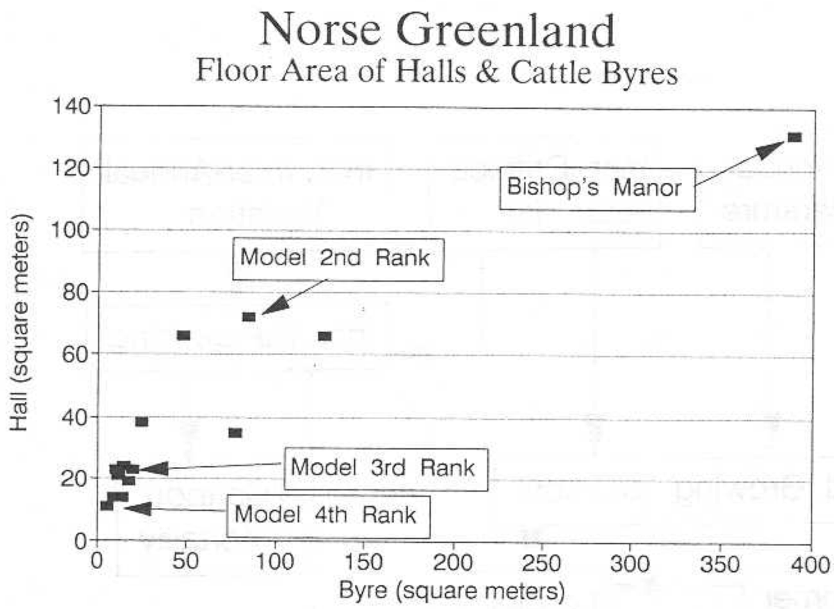

Figure 1. The interior floor area of excavated Norse ruins has been used as a measure of site rank. Hall area is a proxy measure for "human space," while cattle byre area is a proxy measure for "cattle space." The bishops' manor at Ø47 Gardar was far larger than any other Greenlandic site by all architectural measures.

to make any pretense of affecting the ways the settlements were run (Durrenberger 1985, 1991).

After 1264, both Iceland and Greenland became part of the Norwegian state, but perhaps more important was the establishment of a bishop (imported from Norway in exchange for a live polar bear, cf. Jones 1985) at Gardar in Greenland in 1127. Bishop Arnald and his successors (all Europeans direct from the continent rather than native sons) seem to have won the labor if not the hearts and minds of the Greenlanders in a spectacular fashion. The small turf churches of the early years were replaced by large stone ones, modeled directly on the latest continental designs and complete with imported stained glass, bronze church bells, and a horrific consumption of prime building lumber in this timber-poor landscape (Roussell 1941). To give an idea of relative scale, the cathedral of St. Nicholas at Gardar was nearly as large as either of the cathedrals of Iceland, nor was it the only major stone church in Greenland. By best estimates, Iceland's population was around 40,000–80,000 at this time, while Greenland's could never have been more than around 5000–6000 (McGovern 1981).

From a single surviving episcopal steward's account (Bardarsson in Gad 1970) we know that the church owned or controlled about two-thirds of the best land in Greenland by the mid-1300s (but also see Keller 1991 and Arneborg 1991, who argue for a more powerful role for secular chieftains). The bishop (or his secular backer) thus seems to have had both the mortgages and the souls of the majority of the Greenlanders in his keeping by the later phases of the Norse colony. Our archaeological floor area data certainly supports the economic and architectural importance of the bishop's manor by the later phases of the settlement (Fig. 1).

From our available documentary and archaeological evidence, we can thus model a small, but sharply hierarchical society supported partly by native and imported terrestrial species in the inner fjords, partly by marine resources of the fjords and open sea, and partly by a long-range hunt for arctic luxury goods and the transatlantic trade that hunt fueled. How did the transition from Little Climatic Optimum to Little Ice Age affect this small community and its tripartite economy? What portions of the Greenlandic Norse economy (and society) would have been most affected?

Expected Impact Models

It would be methodologically elegant if we had made up our model of expectation, generated some testable implications, and then systematically gathered zooarchaeological, locational, architectural, biogeographical and documentary data to carry out critical tests. However, our research followed no such neat progression, and most of the models that follow were *ad hoc* attempts to make sense of rich, but complex data sets collected under somewhat simplistic initial assumptions. Thus the integrating models presented here are a series of rough and unevenly quantified first attempts, which we are actively attempting to improve.

Following our analysis of the Norse economy and society, we thought it productive to investigate terrestrial and marine resource impacts separately, and to keep the hierarchical structure of medieval Norse society firmly in mind when investigating variation in farming strategy.

The impact of climatic change on Greenlandic biota has been much discussed for many years, as short-term fluctuations have had significant economic as well as ecological effects readily apparent to observers of all sorts (see Vibe 1967, 1978; Mat-

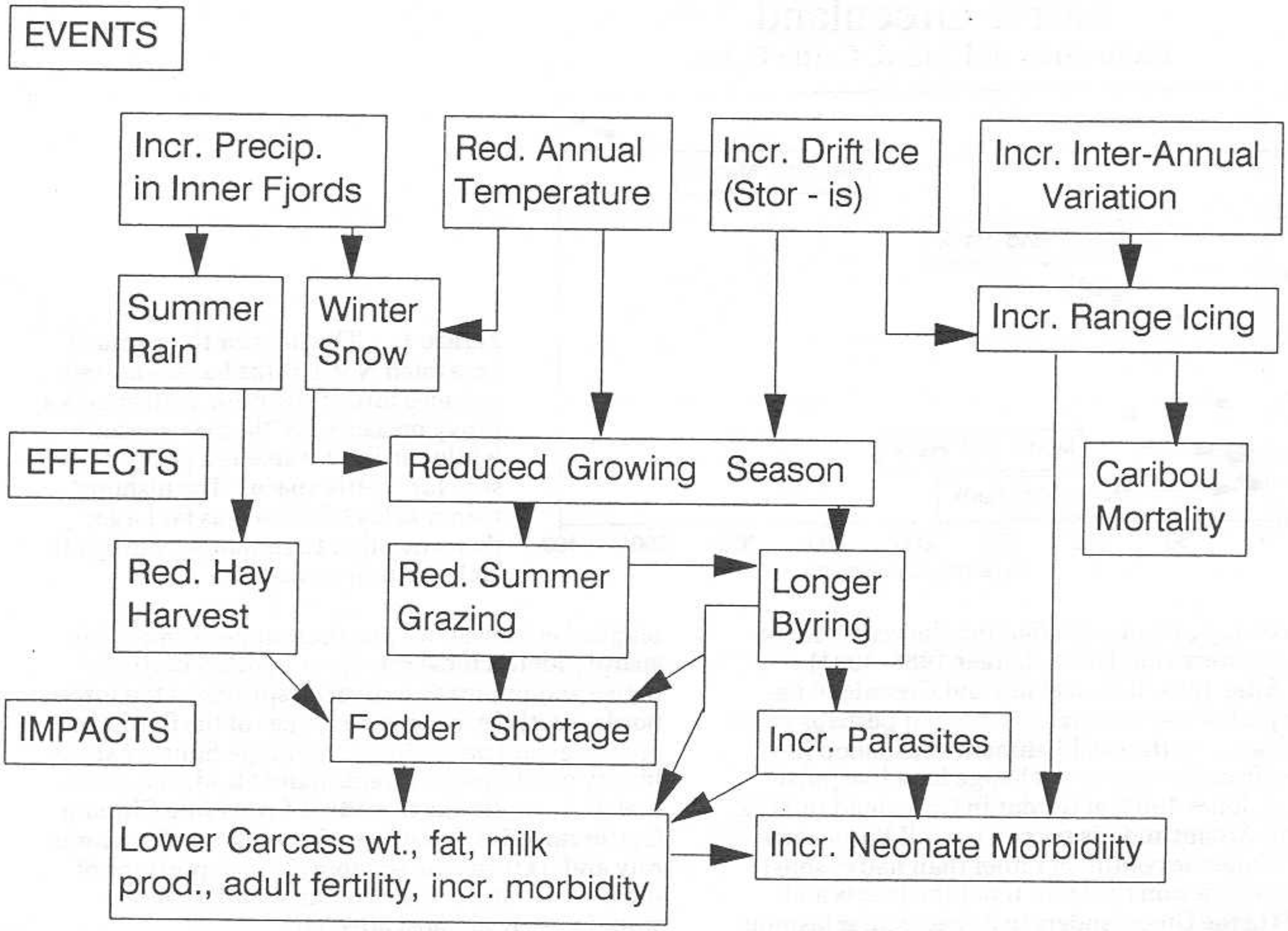

Figure 2. A simplified flow chart identifying the major linkages between climatic events, their effects on local resources, and their expected impact on components of the Norse economy.

tox 1973; M. Meldgaard 1986 for bibliography and review). Changes in overall Northern Hemisphere temperature translate, in Greenland, into shifts in ocean current circulation, which bring greater or lesser amounts of cold East Greenlandic water and ice up the west coast, and shifting air circulation patterns, which tend to reinforce or erode the distinction between continental inner fjords and oceanic coast (Böcher 1954). Shifts between equilibria are often rapid and abrupt. Different portions of the west coast are sometimes affected in concert by the same shifts, sometimes reactions are out of phase.

The two Norse settlement areas appear to have somewhat different controlling variables. The smaller, more northerly, Western Settlement is significantly more restricted to the continental inner fjords than the Eastern Settlement, which reaches well down several of the complex fjord systems of Narssaq and Qornoq Districts. The contrast of maritime outer fjord and continental interior also appears more marked in the Western Settlement, while drift ice seldom reaches the region. The Eastern Settlement area by contrast is much more open to the sea and to the influence of drift ice from East Greenland (the modern *stor-is*). While we will tend to lump discussion of impact in the two settlements, it is well to remember that more detailed research is likely to reveal significant differences in both vulnerability and impact in the two communities.

Terrestrial Impact Models

Figure 2 presents an attempt to identify the kinds of Little Ice Age (LIA) short-to-medium term weather events which would have had direct or indirect effects on the terrestrial portion of the Norse economy as we now understand it. The figure indicates at least the major avenues of possible impact, and owes a great deal to the careful documentation of actual LIA impacts in Iceland carried out by Astrid Ogilvie (1981a, 1981b, 1991), studies by teams led by Paul Buckland, and Gúdrun Sveinbjarnardóttir (Buckland 1988; Buckland, Sveinbjarnardóttir, et al. 1983; Buckland and Perry 1989; Buckland et al. 1991; Dugmore and Buckland 1991) and by an Icelandic team led by Pal Bergthorsson (1985). Some events (increased late summer rainfall) might directly affect the size and condition of the late summer hay harvest (cf. Ogilvie 1981), while events like a cold winter and late spring would both directly affect cattle and caprines byring time and also indirectly affect hay harvest through winterkill of grasses (Bergthorsson 1985; Fredskild 1973) and late thawing of ground.

On the archaeological/anthropological side, we have been working with farm management models[1] to try to understand the effects of climatic impacts on what seem to be the major factors limiting North Atlantic stockraising. These farm management models involve a series of variables with associated assumptions:

(1) *Pasture productivity* is measured in kilos of fodder per hectare: figures here are drawn mainly from Fridriksson (1969, 1972) and the modern Greenlandic experience as noted in Egede (1982). Yield figures are deliberately conservative, and are graded into four pasture categories, ranging from fertilized (and sometimes irrigated) home field (ca. 1050 kg/ha) to low-quality upland herbslope (ca. 200 kg/ha). See McGovern et al. 1988 for further discussion.

(2) *Catchment estimates of pasture size.* The three size classes—second rank (V51 Sandnes-type), third rank (V54-type), and fourth rank (V35-type)—are presented as ideal types, but pasture area data collected in 1976–1977, 1981, and 1984 from site territories defined by unweighted Von Theissen polygon boundaries provide the underlying proportional estimate (cf. McGovern 1985b; McGovern and Jordan 1981).

(3) *Number of domestic animals and cattle: caprine ratio.* Since cattle could only survive the Greenlandic winter inside insulated cattle byres, and since these byres often have stone stall-dividers, a direct measure of maximum cattle capacity is available for many excavated farms (see McGovern 1985b for discussion). The general ratios of cattle to caprines (probably nearly evenly divided between sheep and goats in the Western Settlement, but predominately sheep in the Eastern Settlement—McGovern 1985b) is derived from ethnohistorical data (Rafnsson 1984) and will be checked against our available archaeofauna, with some allowance for Payne Effect.[2]

(4) *Cattle and caprine fodder consumption rates.* These are rough means, based on a large series of estimates (which range widely) for maintaining fertility and seasonal lactation in traditional breeds in the North Atlantic. See McGovern et al. (1988) for further discussion.

(5) *"Sheep units"* as a measure of human wealth and possible consumption are drawn from Fridriksson (1972), and represent an estimate of the number of sheep (9) needed to support one human largely from sheep products, and the number of sheep needed to equal one cow (6). We know from law codes that wealth as well as nutrition was measured in "legal cattle" in the medieval North Atlantic (Durrenberger 1991; Miller personal communication 1986; Hastrup 1985), so this native category seems a reasonable currency in which to measure relative contribution of domestic animal products to diet and general wealth of the farm. Note that cattle were clearly more highly valued and prestigious in traditional North Atlantic agriculture, and a medieval farmer would probably reckon in cattle units. He would also certainly tend to cull caprines before cattle in attempts to cope with fodder shortfalls.

(6) *Farm household size.* Estimates of North Atlantic farm household size based upon documentary sources vary widely (Thorarinsson 1961), and we know that large and even medium-sized farms employed numbers of impoverished servants and laborers. Estimates here are based upon the floor area of the hall, one room whose function can be readily established in excavated examples, with some allowance made for the "festal" functions of the second-rank farm (Berglund 1982; Roussell 1941).

(7) *Tithes and rents.* We know the approximate amount of rent and church tithe payments from Icelandic law codes, chiefly *Gragas* (Hastrup 1985). Tenants owed 10% of the total value of their holding per year, and everyone owed a tithe to the local church farm, which sent a portion on to the next higher ranking church. In practice, additional rents, fines, and special collections tended to raise exactions far above the conservative 20% maximum figure used here.

A Crude Economic Model

Putting these variables together in a spread sheet format, we compared the stockraising conditions and general wealth of three sample farms (Fig. 3). The second rank farm is modeled on V51 Sandnes, a chiefly church farm drawing tithes and some rents from a parish and owing tithes to the first rank episcopal manor at Gardar (omitted here). The third rank farm is modeled on medium-sized Greenlandic farms like V54. In our model, it owes tithes to the second rank farm and collects rents from one fourth rank farm (thus representing a middle-ranking free holder). The sample fourth rank farm probably represents the majority of steadings (at least in the Western Settlement). In our model, the farm owes both tithes and rents and has small and none too productive pastures. A fifth rank might be added at the bottom (McGovern n.d.), and the first rank farm at Gardar (Ø47) should be added at the top. However, we have omitted these extremes for the time being in this first-stage approximation.

Figure 4 illustrates the effects of the model's maximum stocking strategy (Fig. 3) on fodder reserves available to major domesticates (limited here to cattle and caprines) and the human "sheep unit" measure we are using as proxy for both por-

FARM MANAGEMENT MODEL

	Second Rank Farm (Sandnes-type)		Third Rank Farm (V54-type)		Fourth Rank Farm (V35 type)	
ANIMALS		ratio		ratio		ratio
Cattle	30	1.23	9	3.33	4	4.50
Caprines	37		30		18	
FODDER REQUIRED						
Cattle	132000		39600		17600	
Caprine	25900		21000		12600	
Total	157900		60600		30200	
PASTURE AREA	1.00% of max. est. size (x 100)					
Hectares	400		175		120	
PASTURE QUALITY	1.00% of max. normal yield (x 100)					
(kg/ha)	%	kg	%	kg	%	kg
1050	10	42000	5	9188	0	0
400	35	56000	30	21000	5	2400
300	50	60000	50	26250	50	18000
200	5	4000	15	5250	45	10800
TOTAL	100		100		100	
YIELD		162000		61688		31200
Fodder reserve		4100		1088		1000
% reserve/shortfall		2.53		1.76		3.21
"Sheep units" (+cows)		217		84 tithe		42 rent & tithe
Tithes and rents owed		36		9 0.10		8 0.20
Tithe and rent income		142		11		0
Available "sheep units"		323		85		34
Human "sheep units" req.		173		72		33
Human reserve/shortfall		150		13		1
% reserve/shortfall		86.92		18.06		1.82

Figure 3. A spreadsheet model for farm management constraints on three site classes.

tion of diet provided by domesticates and of general wealth. Not surprisingly, the model predicts that the richer pastures and substantial income of the second rank farm would provide a significant surplus above the needs of the large manor household, while the fourth rank farmer would just about break even.

In reality, it is unlikely that this model maximum stocking strategy could have been long practiced, even during the Little Climatic Optimum (LCO), since even minor declines (10% or less) in pasture productivity would require stock reduction in all farms, and the majority of farmers would certainly need to supplement their "sheep units" with other resources—such as the seals and caribou recorded in both medieval documents and excavated archaeofauna.

This simple model suggests that the Norse subsistence economy certainly could absorb fluctuations in pasture productivity in the 10–20% range as long as some caribou and seals were available to prop the terrestrial/stockraising sector. During favorable periods, the economy as modeled would even generate the sort of extractible surplus that could fuel chiefly ambitions and episcopal building projects, as well as allow some modest alms to be recycled to the deserving poor.

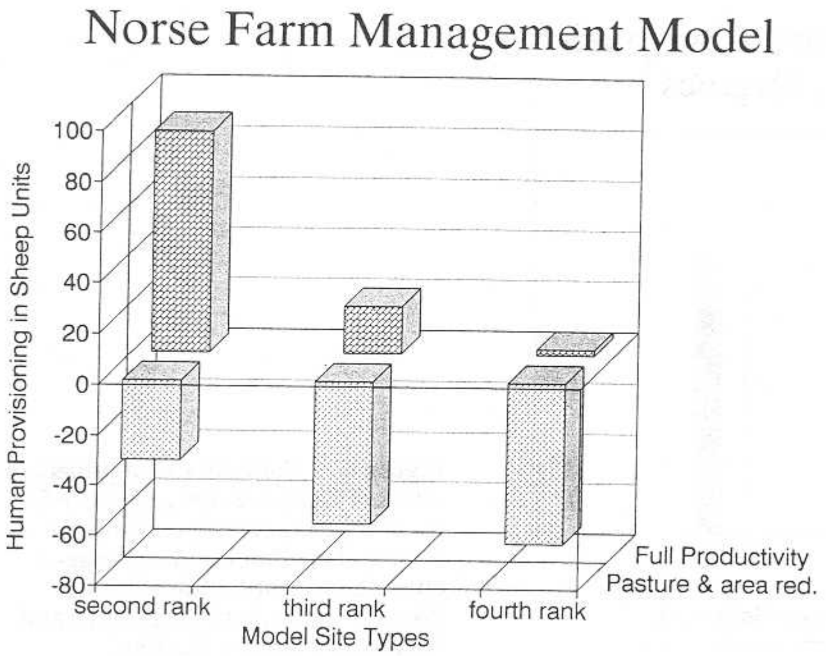

Figure 4. The modelled effects of a 60% reduction in pasture productivity and 10% reduction in pasture area (front bars) on the "full productivity" scenario produced by the farm management model (back bars), measured in sheep units.

Modelling Little Ice Age Impacts

But what of LIA impacts? How would this imported farming economy face a really major decline in temperature and pasture productivity? To answer these questions we need to estimate the difference between LCO, Modern, and LIA average temperatures, and find a method for transforming these temperature changes into changes in pasture productivity.

Awaiting expected help from climatologists, we will simplistically use Lamb's (1977) often quoted estimate of LCO average temperatures around 1° C higher than modern (the latter being defined as the 1930s–1950s warm period) and LIA average temperatures around 2° C lower than the modern warm period (cf. Ogilvie 1991). Two methods of temperature/pasture productivity transformation are available: accumulated temperature and winter temperature effect (Bergthorsson method).

The first method (traditional in agricultural climatology) focuses upon the summer growing season, using a measure of accumulated temperature above the vegetative threshold (ca. 5° C for pasture grasses), counted in day/degrees (Smith 1975). For baseline data, we have used temperature tables for the modern settlements of Kapisillit (1939–1956) and Igaliku (1933–1946), located in the former Norse Western Settlement and Eastern Settlement respectively (Putnins 1970:3–128).

Following Parry (1978), we have used this baseline data to model the impact of possible temperature changes. If we adjust the modern summer temperature data by adding 1° C for LCO and subtracting 2° C for the LIA, we produce the accumulated temperatures presented in Figure 5. The modelled LIA summer temperature reduction would apparently hit the Eastern Settlement slightly harder than the Western Settlement, in either case suggesting something like a 50–60% reduction in accumulated temperature.

More recently, Pall Bergthorsson and other Icelandic scholars have focused their attention on *winter* temperature as a useful predictor of pasture productivity. In a well-supported article, Bergthorsson (1985) presents a series of formulae for calculating winter temperature (October–May) effect on hay yield, derived from a long period of modern observation. Using Bergthorsson's hay yield formula (1985:114; with zero entered for the nitrate fertilizer component), and the same temperature series from the same two Greenlandic stations we can produce another impact model (Fig. 6), this time attempting to predict hay yields directly. Here we see the marked effect of the Western Settlement's much colder winters, uncompensated by the warm summer peak. Not only are Western Settlement projected hay yields much less than Eastern Settlement projected yields during LCO and modern times, but LIA temperatures appear to bring about a crash of Western Settlement hay production into negative numbers.

Neither method has yet been calibrated for the special growing conditions of Greenland's inner fjord communities, and both methods probably overemphasize adverse impact (see McGovern et al. 1988 for discussion), so we cannot simply read off a precise figure for pasture productivity drop. Ogilvie's (1981a) analysis of seventeenth to nineteenth century Icelandic climate impact reports indicates that both winter and summer temperatures had a direct impact on hay harvest, with

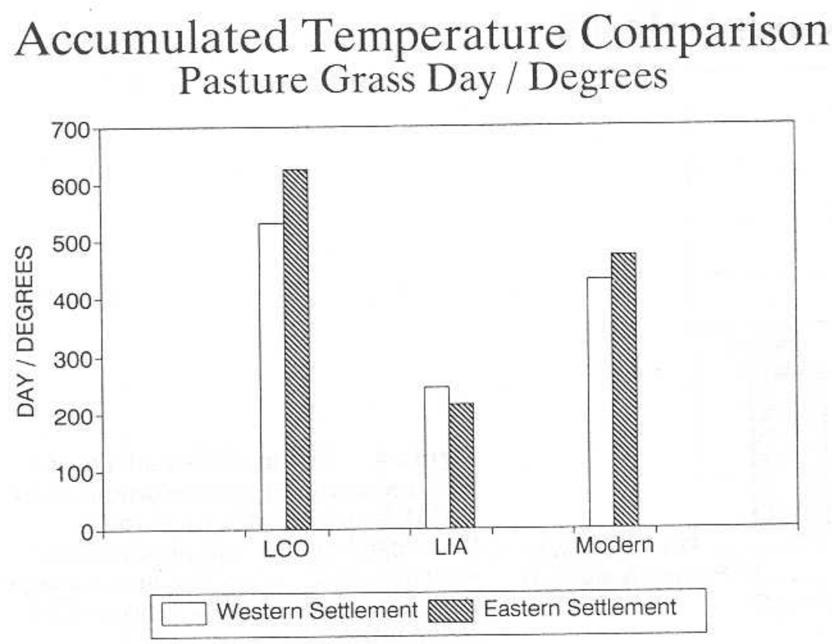

Figure 5. Comparison of projected effect of Little Ice Age and Little Climatic Optimum temperatures on modern baseline Day/Degree accumulated temperatures for the Western Settlement (Kapisillit) and Eastern Settlement (Igaliku).

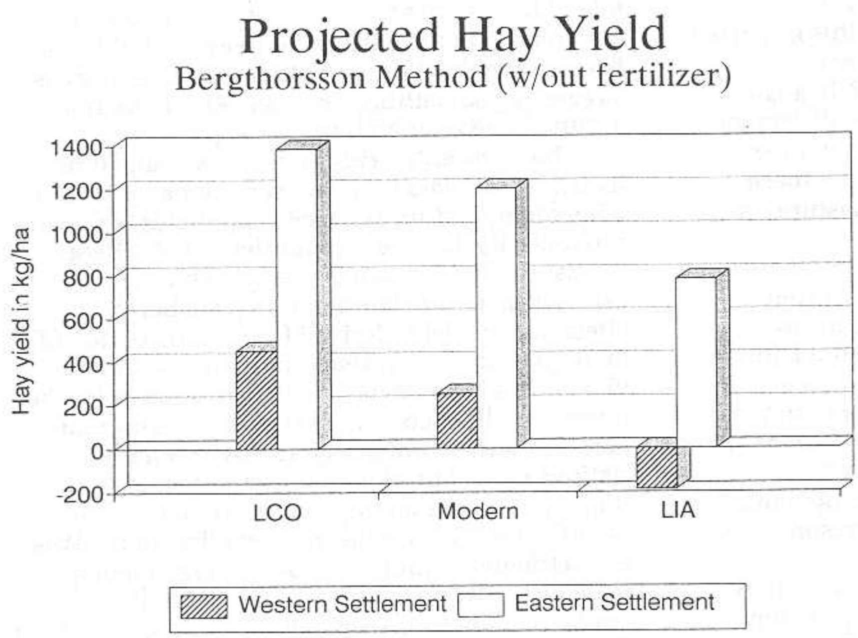

Figure 6. Projected hay yields for the Little Ice Age and Little Climatic Optimum from modern baseline data, using Bergthorsson's method of calculation.

summer temperatures most significant in most districts.

While more investigation is in order, on the basis of current documentary evidence and retrodictive model output, it seems reasonable to imagine up to a 50–60% drop in pasture productivity between LCO and LIA. It also seems likely that the Western Settlement was significantly more vulnerable to winter killing of grasses and lowered productivity (especially if cool rainy summer followed cold winters).

Returning to our three sample farms of our simple production/consumption model (Fig. 3), we can input a 60% reduction in pasture productivity and a 10% pasture area reduction (to simulate the effects of overgrazing and erosion; cf. Fredskild 1982; McGovern et al. 1988) for a worst case view. The model predicts that there is a possible response to even this scale of impact, but it requires major dietary supplement in all farms, and would seem to put lower-ranking farms effectively out of cattle husbandry (Fig. 4). There can be no question that pasture area and productivity reductions on this scale would have a major impact not only on the

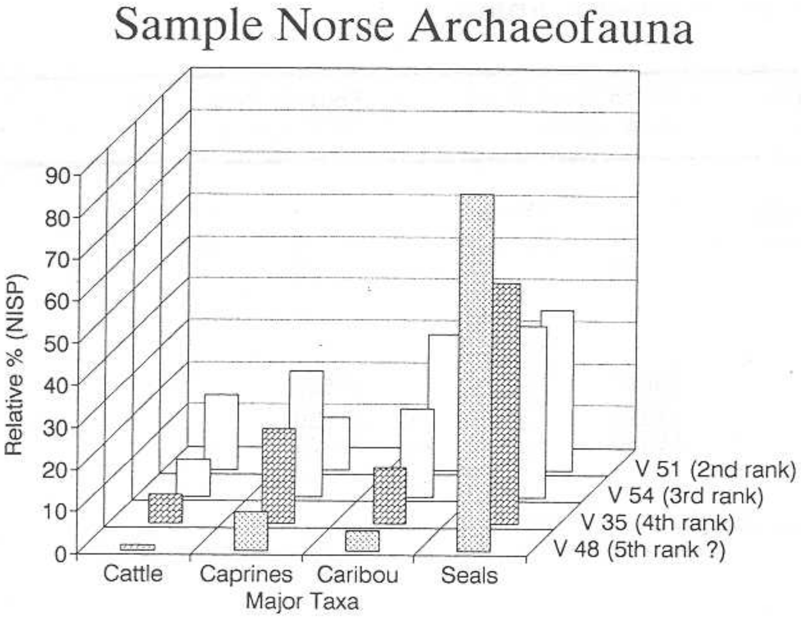

Figure 7. Major taxa of four sample Norse archaeofauna, showing some rank-related variation. Note that 2nd rank sites tend to have more cattle and caribou and less caprine and seal than lower-ranking sites (see McGovern 1985b for data).

wealth of the Norse Greenlanders (as measured in sheep units), but also on the capacity of domestic stock to maintain a biologically viable population size. How realistic does this stock culling response model appear in comparison with our zooarchaeological data?

Zooarchaeological Data

We are fortunate in having a fairly large and well-documented set of archaeofauna for Norse Greenland (see McGovern 1985b for complete data up to 1984), most deriving from the later phases of the Norse occupation. This zooarchaeological data can thus serve as a sort of rough check on the realism of the predictions of our production/consumption models.

The ratio of cattle to caprine bones from our sample of Western Settlement sites (n=8 in late phase), indicates that the better-off Norse may have kept relatively more cattle and fewer caprines than our LIA stock-culling model would suggest. Ratios run from a high of 8 caprine to 1 cattle (V48 phase 4) to a low of 1.4 cattle to 1 caprine (V51), with most sites in the 2–3 caprines per cattle range (mean = 1.8 caprine to 1 cattle). Even allowing for the Payne Effect noted above, it would appear that upper and middle ranking farmers managed to keep more cattle than we would expect. However, on one very poor site we do see some evidence for the movement to thriftier caprines predicted by our model.[3] This Western Settlement site, V48 Niaquussat, provides a stratified midden sequence from first settlement to final phases (McGovern et al. n.d.). Its lowest layers show a ratio of caprines to cattle of about 2:1 and its upper layers a ratio of about 8:1. It may be that upper-ranking farmers had access to fodder resources not included in our count (especially highland meadows and seaweed), and that the tithe and rent structure was significantly steeper than we have modeled.

Even in its crude state, our farm production/consumption model strongly indicates that all the farm households would require a significant supplement to available sheep units, and that this supplement would be most necessary in hard stock-raising periods. We would also predict that poorer farms would need the most wild food for survival. Turning again to the zooarchaeological collections (most presumably from LIA periods), we can see these model predictions at least partly fulfilled. Figure 7 presents the relative percentage of major taxa for the second rank site V51 Sandnes, the third rank site V54, the fourth rank site V35, and what was probably a fifth rank site at V48 (phase 4, ca. A.D. 1300–1350). In each case the role of seals would appear to become more and more important as we descend the social scale and as the quantity and quality of pasture for domestic mammals declines.

Marine resources, especially seals, seem to have played a critical backup role to the Norse herding economy in normal times, and that backup appears to have been particularly critical for the poor-middle ranking majority during hard times. It thus would seem useful to investigate possible climatic impacts in the marine sector.

Marine Impact Models

Our marine resources model is rather less complete, and is largely based upon a twenty-year sequence of catch returns from the Ministry for Greenland's *Summary of Catch Statistics*, which

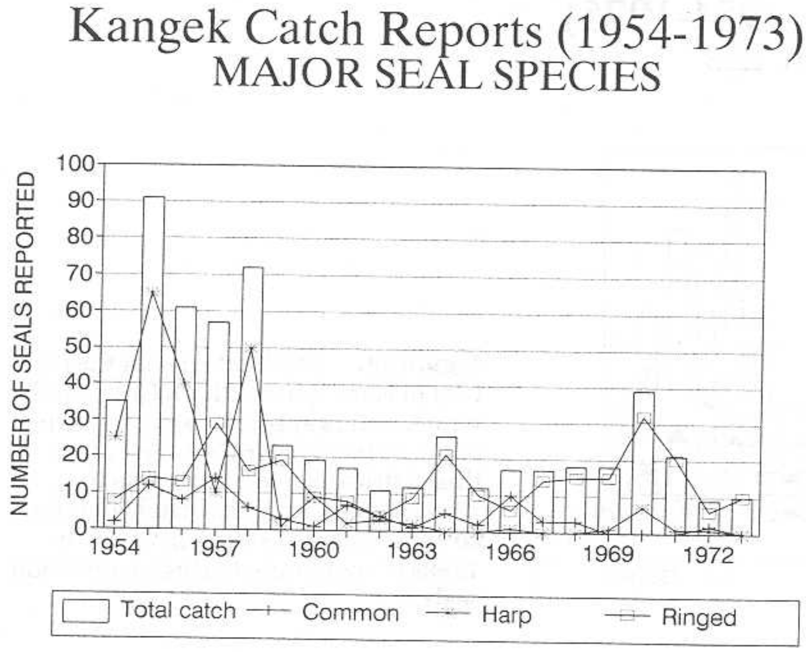

Figure 8. Catch returns for the outer fjord community of Kangek, 1954–1973. Note the decline in harp seal catch in the late 1950s. Community abandoned 1973.

has its own interpretive problems. These data indicate first that modern Greenlandic Inuit hunters take a somewhat different range of seal and other sea mammal species than did the Norse, and second that the species most vital to Norse subsistence (harp, hooded, and common seals) do show some marked variability in catch rate. There are significant problems in directly linking complex marine food webs to annual variation in air temperature, but it does appear that a consistent pattern relating to the cooling (ca. 1° C) observed in Greenland since the late 1950s can be seen at a number of stations.

Christian Vibe's classic work (1967) analysing Greenlandic animal population fluctuations in relation to climatic changes has been much cited by arctic researchers interested in climate impact (Fitzhugh 1972; McGovern 1981). Based on modern catch records and Royal Greenland Company hide purchase data, Vibe constructed a three-phase marine impact model, since simplified to a two phase model (Vibe 1978). While there are certain pitfalls inherent in using catch reports as a proxy for animal abundance (discussion in McGovern 1985a), biologists generally have found this modern data base extremely useful.

Patterns in the Modern Seal Catch Returns from the Former Western Settlement

Using the annual catch reports published for 1954–1975, we can attempt to relate Vibe's general model to specific localities within the Norse settlement areas. Ecologically, the fjord systems of the Norse Western Settlement divide into four zones:

(1) *Maritime Outer Fjords* —the shatter of islands at the very outermost portion of the fjordmouth, including the seaward edge of the barren Nordland peninsula; represented by the small community of Kangek (abandoned 1973).

(2) *Maritime Fjordmouth* —Islands and indented mainland coast within the outermost islands; represented by the large (and growing) town of Nuuk (Godthaab), the present capitol of Greenland.

(3) *Semicontinental Mid-Fjords* —a transition zone between the maritime outer fjords and the continental inner fjords; represented by the small settlement of Qoornoq (abandoned 1971).

(4) *Continental Inner Fjord* —continental zone at the head of the deeper fjords, abuts the ice cap. This was the zone of Norse farm settlement, and is represented by the small settlement of Kapisillit (includes Neriuniaq).

Figure 8 presents the number of individuals of the most common seal species reported at the outer fjord station of Kangek. Note that during the warm 1950s the total seal catch (uppermost line) was largely dominated by the migratory harp seal (*Pagophilus groenlandicus*). After the late 1950s–early 1960s cooling trend began (Vibe's phase C_v / A_{vi} transition point), there was a marked decline in total seal catch, and this total figure was dominated by the ringed seal (*Phoca hispida*).

Figure 9 presents the same data for the fjordmouth station of Nuuk, and again the late 1950s showed a marked decline in harp catches and a parallel increase in ringed seal catch (no catch records were kept for the year 1970). The failure of the harp seal hunt was noticeably less profound than at Kangek (Fig. 16).

Figure 10 presents the same data for the midfjord station, Qoornoq. Here the harp seal crash of

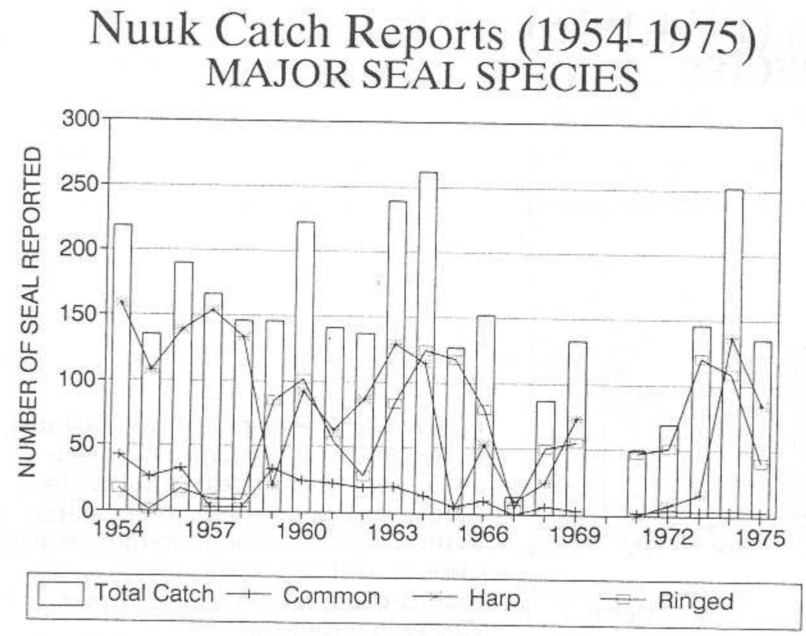

Figure 9. Catch returns for the fjord-mouth community of Nuuk, 1954–1975. The harp seal catch becomes highly variable after 1959, and the ringed seal catch begins to increase.

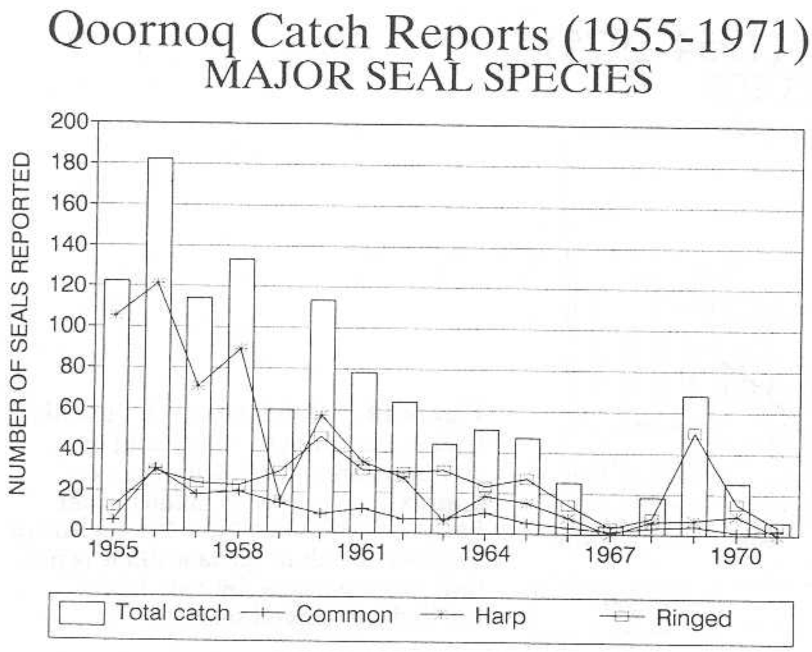

Figure 10. Catch returns for the mid-fjord community of Qoornoq, 1955–1971. The reduction in harp seal catch in the late 1950s–early 1960s is not effectively compensated by an increase in ringed seal hunting. Community abandoned 1971.

the late 1950s resulted in a drastic reduction of total seal catch, though there were some weak signs of a ringed seal substitution just before abandonment in 1971.

Figure 11 presents the same data for the inner fjord station of Kapisillit, in the heart of the old Norse Western Settlement. Here harp seals have always been of secondary importance, but the failure of the harp migrations after the late 1950s left the total seal catch nearly wholly dependent upon the ringed seal.

These data would suggest that climatic fluctuations on the scale of the cooling of the north in the early 1960s would have a noticeable effect on Western Settlement sealing. Harp seal migrations would pause for a shorter time in the region, and the seals would penetrate far less deeply into the mid-fjords and inner fjord zones. Harp sealing would remain most profitable in the fjordmouth zone, some 70 km from the center of the Norse settlements in the inner fjords.

It is certainly no accident that two Western Settlement Norse sealing stations (probably occupied seasonally) are located in this fjordmouth

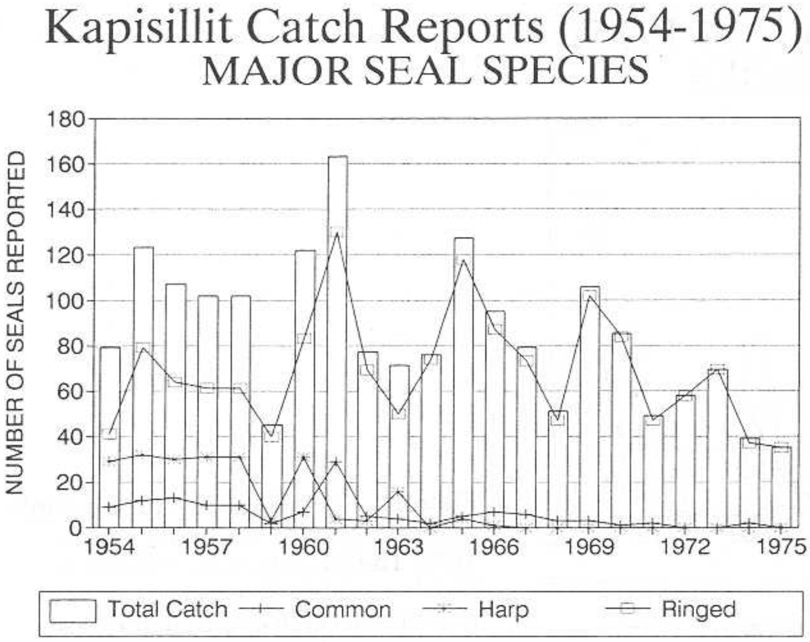

Figure 11. Catch returns for the inner fjord community of Kapisillit, 1954–1975. Harp seals appear to always be a secondary resource, and their decline in the 1960s does not profoundly affect the total seal catch. This modern community occupies part of the former Western Settlement.

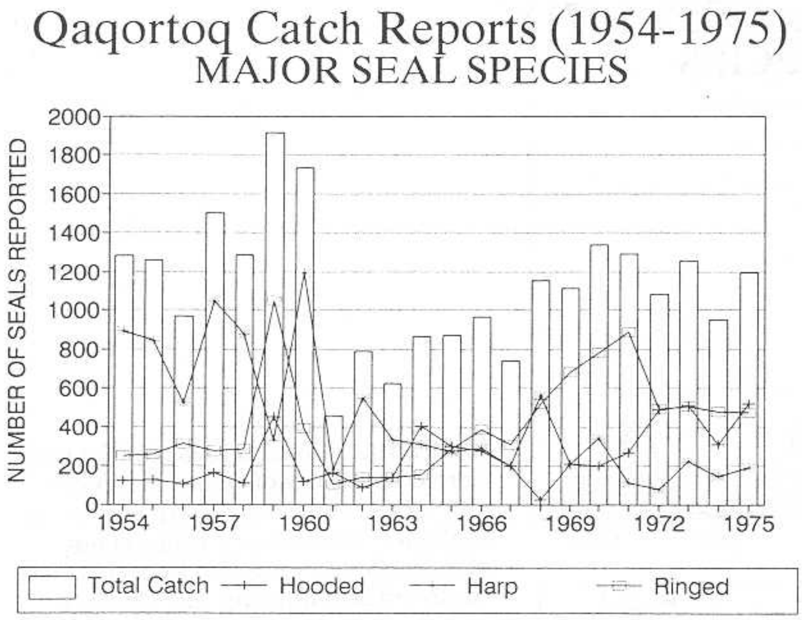

Figure 12. Catch returns for the district of Qaqortoq (Julianehaab) in southern Greenland, which covers approximately a third of the former Eastern Settlement. Note the decline in harp seal catch in the late 1950s is partially compensated by a switch to hooded and ringed seal hunting.

zone (McGovern 1981; Gulløv 1983). Such stations would provide a center for hunting parties and a cache point for carcasses, but their distance from the home farms must have raised the costs of seal exploitation for the Norse settlers.

Patterns in the Modern Seal Catch Data from the former Eastern Settlement

In the former Eastern Settlement area (modern Narssaq and Qaqortoq districts), fjord configuration is more complex and the mix of seals different. However, this region shows some parallel fluctuations in reported seal catch. Figure 12 presents seal catch data for Qaqortoq district (largely mid-fjord to fjordmouth). Note the shift from a total seal catch dominated by harp seals in the mid-1950s to a catch made up of ringed and hooded seals after the cooling episode.

Figure 13 presents the same data for Narssaq (largely mid-fjord to inner fjord), and again we see a catch shifting from harp seal dominance to ringed seal, in this case boosting total catch significantly. Note the important role played by ringed seal as a reserve resource in many of these modern

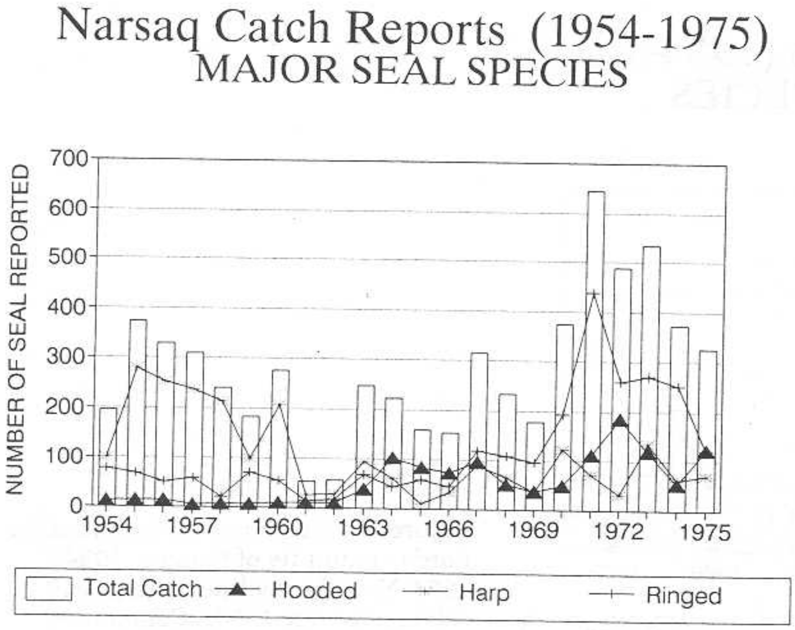

Figure 13. Catch returns for the district of Narsaq in southern Greenland, which covers approximately a quarter of the former Eastern Settlement. In this district, hunters were able to increase their total seal catch after the collapse of harp sealing in the early 1960s by switching to ringed and hood seals.

Inuit Greenlandic contexts, most dramatic in this district.

Increased interannual variability in timing and location of seal migration would further complicate the planning and management of Norse sealing. Analysis of coefficient of variation for the six reporting regions indicates significantly greater interannual variation in harp seal take after 1958. It is possible that similar increases in variability were associated with similar climatic transition points in the past.

Interpretation of Overall Impact of Sealing Fluctuation

While these data (and their limitations) deserve further discussion, we can make the following statements about possible maritime resource impacts:

(1) As Vibe (1967 et seq.) has noted, patterns of seal accessibility at a given point seem to fluctuate between two to three metastable equilibrium states, with periods of highly variable instability between.

(2) In the two Norse settlement areas, these equilibria are slightly different, due to the different migration pattern of harp and hooded seals. Hooded seals are rare during all periods in the Western Settlement area.

(3) Temperature fluctuations on the scale of the modern post-1960s ca. 1° C cooling seem to produce changes in equilibria. Judging by oxygen isotope curves (Dansgaard et al. 1975) more major shifts occurred during the LIA, and interdecadal variability during the fourteenth century may have been extreme (Dansgaard in Lamb 1977:99).

(4) In the Eastern Settlement, warmer conditions seem to produce high and fairly stable harp seal catches, while cooler conditions produce higher hooded seal catches. Common seal catches today are consistently low in this area, probably because of the frequent occurrence of summer drift ice in optimal common seal breeding areas.

(5) In the Western Settlement, warmer conditions seem to produce high and consistent harp seal catches, except in inner fjord stations, and common seals also seem to be abundant during such periods. During transitional periods, common seal catches and harp seal catches show extreme variability, but then settle into a pattern of low frequency in both outer island and inner fjord biomes, but higher frequency in the fjordmouth zone.

Periods of instability or low accessibility of seals from the inner fjords (where the Norse farms were) would present a challenge to Norse subsistence. In the Eastern Settlement we might expect a greater concentration on hooded seals in later phases, and this is just what our single stratified bone collection (Ø17a) from the area indicates: the ratio of hooded seal bones to harp seal bones jumps from 1:19 to about 1:4 (McGovern and Bigelow 1984).

Figure 14 summarizes possible LIA impacts on the marine component of the Norse subsistence system in Greenland. It would appear that the onset of the LIA produced a net increase in cost and risk in marine resource exploitation. This increased hazard and exploitation cost does not appear to be balanced by a greatly increased return. As crews had to hunt farther from the settlements, and likely had to extend the sealing season in attempt to maintain yields, the risk of potentially devastating loss of life and boats in a major maritime disaster would steadily increase.

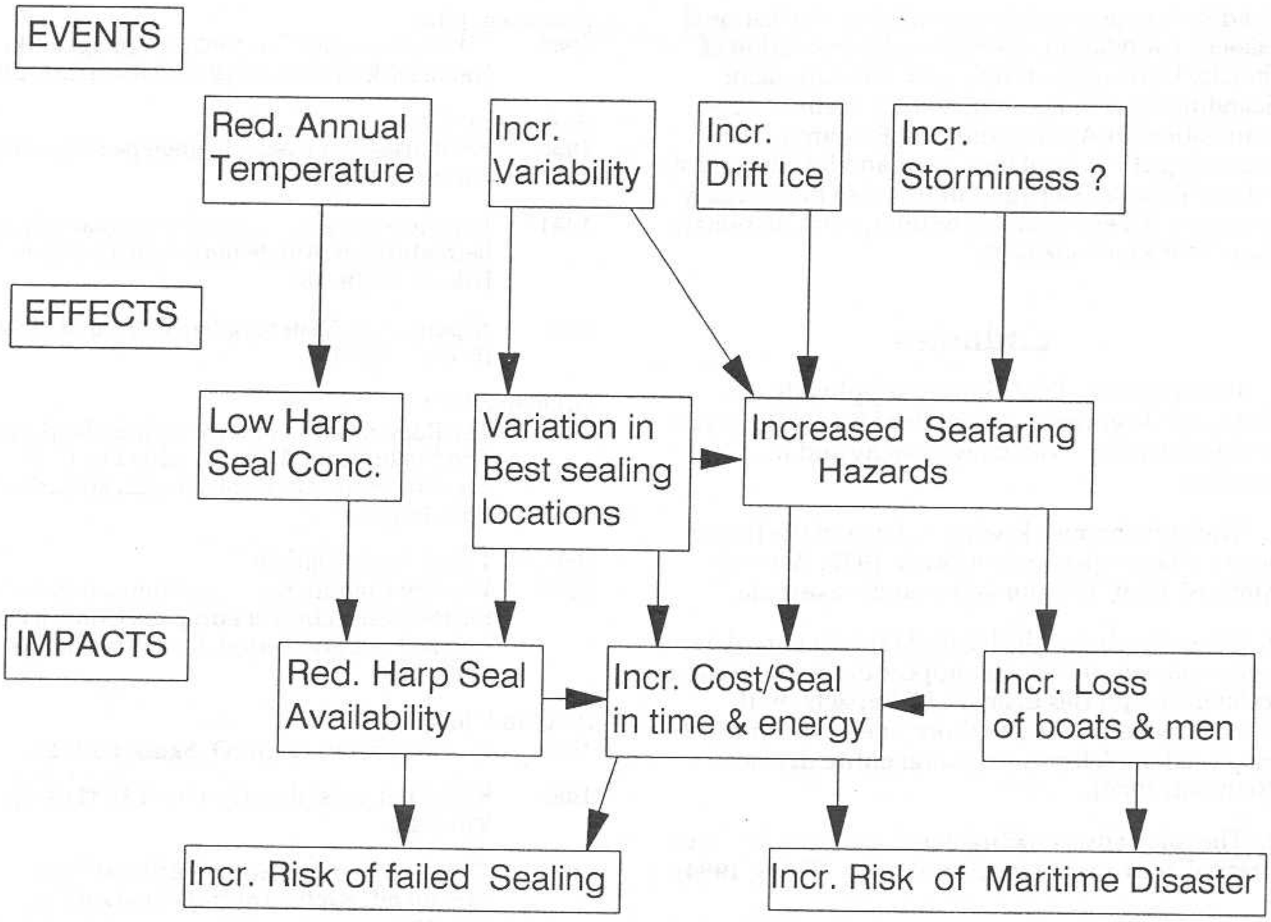

Figure 14. A simplified flow chart identifying major linkages between climatic events, their effects on portions of the marine ecosystem, and the probable impact on portions of the Norse marine hunting economy.

Caribou Predation and Climate

Our available archaeofauna indicate that caribou played a major role in Norse subsistence in the Western Settlement, and had at least some role in the Eastern Settlement as well. Blinds, cairn line drive systems and highland caches are all documented in the Western Settlement (McGovern and Jordan 1981; Christensen 1991), and it would appear that communal hunts were a regular feature of the seasonal round. How did local caribou populations respond to this steady human predation and a changing climate?

An excellent recent study of Greenlandic caribou population history and dynamics (M. Meldgaard 1986) sheds some light on this question. Using archaeological and historic sources as well as the Ministry for Greenland catch statistics employed above, Morten Meldgaard documents the highly variable "boom and bust" fluctuation of West Greenland's caribou populations during the past 250 years. Periods of caribou abundance characterized by large, seasonally migrating populations of large individuals punctuate longer periods of low population density, limited or absent seasonal movement, and generally smaller individuals. Transitions are short, and marked by catastrophic population crashes (see Spiess 1979 for similar findings elsewhere). Meldgaard notes the effects of disease, insect disturbance, overhunting, and range overgrazing, but concludes that climatic change is the most significant variable, and the only variable that can explain the documented tendency for West Greenland caribou populations to boom and crash in phase. Whether small survivor populations can remain to fuel the next boom or whether the local population is driven to extinction (as were the caribou of the former Eastern Settlement area in the nineteenth century) appears to be determined by other variables (especially hunting pressure).

Since the farming Norse thoroughly occupied the inner fjord "refuge zones" to which remnant caribou populations tend to retreat in hard times, and since they kept dogs and flocks which would tend to harass and compete with the caribou,[4] and since they certainly hunted the animals intensively, we would expect the Norse to have pushed local herds to extinction promptly after the first hard winter. However, we know that this did not happen.

Our bone collections are mainly from the later phases, presumably deposited during hard times and after a number of probable boom and bust cycles must have played themselves out. There are substantial numbers of caribou remains in these collections, even from the climatically vulnerable Eastern Settlement area, where Inuit hunters armed with muzzle loaders finished off nineteenth century survivor herds. In addition, the individual animals seem large, fully as big as the modern, boom period specimens of Nuuk district (see M. Meldgaard 1986 for metrics; more abundant nonmeasurable fragments lend further support). Had the Norse pushed these animals to the brink of extinction (or over, as seems all too likely), we should see a different pattern in the archaeofauna.

An explanation for this phenomenon may lie in the social, rather than the climatic realm. As argued above, Norse society in Greenland was sharply hierarchical, with a strong degree of social control evidenced by the massively disproportionate building projects. Our available bone collections indicate that the Norse elite may also have had a disproportionate interest in caribou predation, and a strong control over it. Though they are normally not well placed to intercept caribou, elite sites in both settlement areas tend to have a higher relative percentage of caribou bone in their archaeofauna than smaller sites placed next to drive systems or otherwise well-situated for upland hunting. As dead seals were moving up into the mountain valleys from the fjords, it would appear that dead caribou were also moving down.

Since the Greenlandic bishops, bishops' stewards, and royal officials were assigned directly from the continent, they certainly brought with them a contemporary model for administration as well as the updated church plans and fashions in dress we can document archaeologically. Game management, especially of deer suitable for elite consumpion, was a significant royal and ecclesiastical concern since at least 1100 in many parts of Europe. Popular legend aside, the often draconian game laws of the continent certainly had the effect of providing at least seasonal refuge for species under increasing pressure from expanding human settlement (Platt 1978).

Whether imposed from above or the result of traditional communal regulation of mountain (jointly owned?) resources, human hunting regulations designed to prevent extinction and provide sustained yield would certainly mitigate the effects of climatic impact on local caribou herds. Social stratification and a concomitant willingness and ability to impose sanctions can certainly have a positive effect on resource regulation (cf. McGovern n.d.).

Transatlantic Trade

We can simplify the climatic aspects of a transatlantic trade model to a single statement: icebergs are bad for ships. There is good reason to believe that the modern summer drift ice which makes navigation in Danmark Strait and the Eastern Settlement area hazardous is a LIA but not LCO phenomenon (cf. Bardarsson in Gad 1970; Ogilvie 1981a, 1981b; McGovern 1985a). Contact with Europe certainly was affected by significantly worsened summer sailing conditions.

Other factors also affected the cost/risk assessments of continental traders: changing fashions; alternate sources of arctic products; and the disruptions brought about by warfare and disease (Keller n.d.). While drift ice certainly played a role in transatlantic voyaging, considerations of profit and perhaps doctrinal orthodoxy may have already made Greenland a less attractive destination for fourteenth century merchants (Arneborg 1991).

Impact and Response

All of these models leave one with the feeling that the LIA would indeed have had a major impact upon the subsistence and exchange economy of Norse Greenland as we now understand it. While the subsistence economy (as we have modeled it) could have survived periods of prolonged reduction in pasture productivity and the occasional failure of the spring seal hunt, the margin of safety and flexibility would have been worn very thin, especially for the smallholder. Challenges from other agents (disease, Inuit contact, etc.) would have been met by a far less prosperous and secure community.

So, after all this care for theoretically correct approaches and years of field research, lab analysis, and hopeful model-building, have we come no further than that simple statement: "it got cold and they died"? We have indeed.

We now can begin to demonstrate linkages between specified climatic impacts and specified elements of an economic model we have some cause to trust. We have good reason to hope that better climatic data as well as better archaeological data can be incorporated into better models in the near future. Now we are in a position to effectively use the high-resolution paleoclimatic data soon to become available.

Just as importantly, we can now be pretty sure that it was not the LIA *alone* which ended Norse Greenland. Added to the farming problems were some culture-contact problems. We know that

Thule Inuit moving into Greenland from Ellesmere in the North were in contact with the Norse hunters by ca. 1170, and both caribou camps and winter settlements further south along the west coast have been radiocarbon dated to the 1200s (Schledermann 1990). Not all the contact was hostile, as there are stories of Inuit servants on Norse farms, and Inuit Thule sites in Greenland as well as in arctic Canada have turned up a wide range of Norse artifacts, some at least the result of exchange. We even have Inuit carvings of a Norseman in his woolen robes (Sabo and Sabo 1978), much like the actual clothing recovered from the frozen graves at Herjolfsnes (McGhee 1984; McGovern 1985a)

Most odd is the relative lack of evidence for contact from the Norse side: if it were not for a few stories and the clear Inuit evidence of face-to-face contact, we would be inclined to assume that no contact had taken place at all. There is no evidence of skin boats, despite clear indication of a shortage of traditional Norse wooden boats, no evidence for the use of efficient Inuit skin clothing, and most significantly, no evidence at all for harpoons or any of the other highly evolved sea mammal hunting gadgetry of the Thule Inuit.

The lack of harpoons and breathing hole and *sina* hunting gear was a serious subsistence problem for the Norse. Despite the importance of seals, Norse communal sealing strategies seem to have largely missed the ringed seal, which played such a key role in both traditional Inuit winter hunting and in buffering the recent climatic transition. If we factor out ringed seal from the modern catch data there is little left of the total seal catch at many modern stations after the mid-1960s. Lacking harpoons and related gear, the Norse also missed a major food source, apparently spending their winters playing chess and hauling blocks of stone for the newest episcopal building project.

In any case, the Norse churches are vacant today, as the smaller Western Settlement became extinct (apparently fairly suddenly) ca. 1350, and the Eastern Settlement was over by about 1450. All available evidence indicates that the Norse simply died out, maintaining ethnic purity to the end rather than merging with the Inuit either biologically or culturally.

Greenland did not become uninhabitable during the Little Ice Age; it simply became significantly more hostile to the established Norse subsistence system, especially to the traditional North Atlantic domesticate component. The Inuit seem to have responded to fluctuations in seal and caribou populations by maintaining a high degree of coastal mobility, shifting north or south as conditions shifted. They had no immobile investment in cattle byres, fertilized infields or large stone churches to tie them to the most vulnerable of Greenlandic biomes.

The Norse Greenlanders with the most to lose from a devaluation of pasture and domesticates were the very ecclesiastical and secular elite who owned land and souls, and who also controlled the communal labor that brought in the hay, caribou, and seals. Even if hellfire and churchly *auto da fé* held no terror for the deviant small farmer seeking other alternatives, exclusion from such communal subsistence activities would have meant certain starvation in short order (McGovern n.d.).

But it is also well to remember that Norse Greenland did last for about 500 years, and in its initial phases a good deal of adaptive flexibility was shown in modifying Icelandic patterns to take advantage of Greenlandic resources. Both secular and ecclesiastical elites were responsible for managing their own estates as well as absorbing the meager surpluses of the less fortunate, and they too must have faced the practical problems of fodder harvest and cattle fertility.

Total extinction is bad for everyone, not just for those who starve first. Many generations of Norsemen endured and coped with the spikes and troughs of temperature variation before final extinction; they did not perish with the first cool breeze of climatic change.

Why then didn't the elites take the course so obvious from hindsight and expand interaction with the Inuit? The Thule could offer expanded mobility on both water and ice, a series of important improvements in winter survival gear, and access to the meat and fat of both ringed seal and bowhead whale. From recent work on the Danish colonial sites of the 1720s (Gulløv and Kapel 1979), it is clear that the later Scandinavian sailors and farmers learned more about harpoons and ringed seals in three years of contact than the Norse did in 30 decades, and when the early missionaries traveled, they used umiaks by choice. Nobody would credit these eighteenth century opportunists with an enlightened or tolerant view of Inuit culture or lifeways, yet they rapidly fastened on just the innovations the Norse tried to live without. What went wrong 300 years before?

These sorts of questions lead to more complex and certainly more interesting avenues than the simple blind end of explanation by correlation. It did get cold and they did die out, but why?

Acknowledgements. The research reported here was made possible and pleasant by the generous cooperation of a host of scholars in North America, the U.K., Denmark, Iceland, and Greenland. The author would particularly like to thank Thomas Amorosi, Claus Andreasen, Dr. Stefan Adalsteinsson, Joel Berglund, Dr. Gerald Bigelow, Dr. Paul Buckland, Dr. William Fitzhugh, Dr. Bent Fredskild, Margaret Hallsdottir, Gudmundur Olafsson, Gudrun Sveinbjarnardottir and Dr. Henrik Tauber.

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Endnotes

1. Without critical data kindly supplied by Dr. Stefan Adalsteinsson and Dr. Bent Fredskild, these models would be even more sketchy and incomplete.

2. The taphonomic skewing in favor of the larger bones of large species; see Payne 1922. Also see Amorosi 1989, 1991 for an Icelandic example.

3. Interestingly (on the basis of fairly incomplete evidence), our model does appear to resemble some Icelandic responses to later LIA impacts, with sheep/cow ratios close to those predicted for third and fourth rank farms in several entire districts (Rafnsson 1984).

4. The role of overgrazing in refuge zones has been stressed as a cause of local extinction (Thing 1984).

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