Landscapes of Settlement in Northern Iceland: Historical Ecology of Human Impact & Climate Fluctuation on the Millennial Scale

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Thomas H. McGovern (1), Orri Vésteinsson (2), Adolf Fridriksson(3) Mike Church (4), Ian Lawson (5), Ian A. Simpson (6) Arni Einarsson (7), Andy Dugmore (4), Gordon Cook (8), Sophia Perdikaris (9), Kevin Edwards (5), Amanda M. Thomson(6), W. Paul Adderley (6),Anthony Newton (4)), Gavin Lucas (3), Oscar Aldred (3)

1) Department of Anthropology, Hunter College of the City University of New York, & Northern Science & Education Center
(Corresponding author: nabo@voicenet.com)
2) Department of History, University of Iceland, Reykjavik
3), Institute of Archaeology, Reykjavik, Iceland.
4) Department of Geography, University of Edinburgh, Scotland UK
5) Department of Geography, University of Aberdeen, Scotland UK
6) School of Biological and Environmental Sciences, University of Stirling, Scotland, UK.
7) Mývatn Research Station, Skútustaðir, Iceland.
8) Scottish Universities Environmental Research Centre, East Kilbride, Scotland UK
9) Department of Archaeology and Anthropology Brooklyn College of the City University of New York & Northern Science & Education Center

Abstract

A thousand years ago Viking age voyagers crossed the grey waters of the North Atlantic, colonizing the Faroes, Iceland, Greenland, and Vinland between AD 800 and 1000. However, early transatlantic migration was not to have the historical impact of the later European re-discovery of North America, and by the 16th century the Scandinavian North Atlantic island communities had become either extinct or were marginalized colonies of continental states. Climate change and unintended human impact upon island ecosystems have long been proposed as root causes of the decline of the Norse Atlantic colonies, but interdisciplinary research had usually been restricted to short term investigations of single sites. In an attempt to better understand the complex interactions of culture and nature in early Iceland and to contribute a long term perspective to larger issues of sustainable resource use, soil erosion, and the historical ecology of global change, since 1996 the NABO research cooperative has mounted a sustained program of interdisciplinary collaboration focused upon 9th-13th century sites and landscapes in the highland interior lake basin of Mývatn. A multi-site, interdisciplinary, landscape based approach to human-environment interaction on the millennial scale has modified many early assumptions about human impact in the region, while documenting a case of 1200 year-old sustainable management of wildfowl and substantial internal exchange of marine products within 9th-10th century Iceland. Organizational background of the research cooperative and management lessons learned are also presented.

Keywords: Iceland, Sustainability, Historical Ecology, Paleoecology

Introduction- NABO, Global Change, and Historical Ecology in the North Atlantic

Near the close of the 8th century AD, Nordic pirates, traders, and settlers began the expansion from their Scandinavian homelands that gave the Viking Age its name and permanently changed the development and history of Europe. In the North Atlantic, by ca AD 800-850 settlers colonized the islands of the eastern North Atlantic (Shetland, Orkney, Hebrides, Man, Ireland, and Faroes). Iceland was traditionally settled ca.874, Greenland ca. 985, and the short lived Vinland colony survived a few years around AD 1000 in Newfoundland/Gulf of St. Laurence region (Wallace 2000, Arneborg 2000). Around the year 1000 AD, Nordic language and culture extended from the coast of North America to the Baltic, and by 1014 an Anglo-Scandinavian dynasty briefly united England, Denmark, and Norway. However this first connection of old and new worlds proved transient. By the mid 11th century the Vinland colony was abandoned, and by the mid 15th century the Greenlandic colony became completely extinct. Iceland survived as the westernmost outpost of the Viking Age North Atlantic expansion, and the first transatlantic connection between the Old and New Worlds ended in failure. Changes in politics and market forces in Europe played a role in the unhappy end to the “Norse Atlantic Saga” (Jones 1986), but climate change and human environmental impact on island ecosystems were also an important part of the story (Amorosi et al. 1998, Ogilvie & McGovern 2000, Edwards et al 2004, Dugmore et al. 2005).

Prior to the 1970s most scholars of the Viking period were philologists, medieval archaeologists, and documentary historians, and the uneven written record for Viking depredations in Europe and Iceland’s colorful and diverse saga literature tended to dominate discussion of the period (for research history see Friðriksson 1994). Since the mid-1970s research focus has shifted, as multiple projects combining archaeology, paleoecology, and history have been carried out all across the region, producing a richer understanding of the Norse migrations, and placing them more effectively in an environmental and economic context (Bigelow 1991, McGovern 1990, 1995, 2004, Ogilvie & McGovern 2000, Morris & Rackham 1992, Housley & Coles 2004). The Historical Ecology movement (Crumley 1994, 1998, 2001, Baleé 1998, Kirch & Hunt 1997) has come to provide the theoretical underpinning of much North Atlantic archaeological research, a pattern shared by many other regions where archaeology and paleoecology are attempting to connect the long term record of human-environment interaction with present issues of rapid environmental change and human response (Hardesty and Fowler 2001). The movement attempts to combine the interdisciplinary environmental orientation of the best of the processual archaeology of the 1980’s with the concern for contextual history, factional conflict, and politically loaded cultural landscape construction stressed by some post-processualists in the 1990’s- with a clear agenda aimed at integrating archaeology & environmental history within global change research (Amorosi et al 1996, McGovern 1994, Steadman 1995b, Redman 1999, Kirch 1997, Descola & Palsson 1996, Spriggs 1997, Bawden & Raycraft 2001).

The dramatic value of the diverse cases provided by the Norse North Atlantic (initial spread of a homogeneous population into different island ecosystems, subsequent economic & social diversification, and total extinction of the Vinland and Greenland colonies) has increasingly featured in works aimed at a broad audience interested in Global Change topics (Pringle 1997, Redman 1999, McGovern and Perdikaris 2000, Diamond 2005). In the past decade, the North Atlantic has thus become an arena for just the sort of international, interdisciplinary research into long term human-environmental interactions that most funding agencies identify as worthy of Global Change support. This development is itself in part an outcome of early global change funding to archaeology and paleoecology by the US National Science Foundation's Office of Polar Programs (OPP).

The NABO cooperative

The regional research cooperative NABO (North Atlantic Biocultural Organization, *www.geo.ed.ac.uk\nabo*) was formally set up at an NSF supported workshop 1992, but grew out of a meeting in 1988 at Bowdoin College hosted by Gerry Bigelow and Susan Kaplan of the Peary-Macmillan Arctic Center (Bigelow 1991). The acronym means "neighbor" in several Nordic languages, and the group began as a set of informal neighborly collaborations among archaeologists and paleoenvironmental scientists who shared an interest in this vitally important quadrant of the circumpolar north. Scholars working in the North Atlantic had no pre-existing regional framework for communication and international collaboration, and tended to be divided and marginalized in national organizations and associations. NABO was granted five years of start up funding in 1993 by the US NSF Office of Polar Programs as a part of the early phases of the US effort to stimulate regionally based, interdisciplinary projects that crossed the then dauntingly well defended natural science-social science boundary (McGovern 2004). The intent of this grant was to stimulate the sort of large scale cross-cutting interconnections that numerous Global Change research panels had flagged as necessary if the soft and hard sciences were to achieve the level of integration needed to provide decision makers with tools for dealing with the accelerating consequences of rapid large scale linked human-environmental changes that were already apparent in the circumpolar north (*Arctic Climate Impact Assessment* ACIA report 2004). NABO was tasked with providing organization and targeted assistance to the North Atlantic community by sponsoring workshops and meetings, interdisciplinary publication projects, practical logistic support for field projects, opportunities for international student involvement, public outreach, and promoting comparability of basic data sets.

Since 1993 NABO has provided support for field projects in Iceland, Greenland, Northern Norway, Scotland, and the Faroe Islands. The group has contributed to northern education by sponsoring doctoral, MA and MSc. theses in Anthropology, Geology, and Geography in both the US, UK, and Scandinavia, and since 1997 has co-sponsored (with CUNY, the Icelandic Institute of Archaeology, U Oslo, and U Glasgow) an international multi-disciplinary field school in Iceland that has involved students from 26 nations. Since 2000 a special NSF OPP Research Experience for Undergraduates grant to Sophia Perdikaris of Brooklyn College CUNY has integrated classroom, laboratory, and real time distance learning, with Icelandic fieldwork, dramatically changing the lives of highly motivated inner-city undergrads and producing a series of student authored papers and posters (Krivogorskaya et al. 2005, Amundsen et al. 2005, Harrison et al. 2005). NABO has also provided practical logistic support (three jointly purchased and maintained Land Rovers, jointly purchased resistivity instruments, EDM's and GPS receivers; pre-positioned stocks of basic field gear, tents, and provisions), has provided enhanced data comparability through community developed data management software (NABONE), and has held a suite of 22 workshops and conferences since 1992 that have helped forge individual and institutional connections and produced major conference publications (Bigelow 1991, Morris & Rackham 1992, Ogilvie & Jónsson 2001, Housley & Coles 2004, Grønnow et al 2005). NABO interdisciplinary efforts produced the first use in archaeology & history of high resolution proxy climate data from the Greenland ice core projects (Buckland et al. 1996, Barlow et al. 1997, Dugmore et al forthcoming a), and NABO meetings now regularly include representatives of the hard sciences and environmental planners as well as the usual crowd of historians, archaeologists, and paleoecologists. NABO teams have also been successful in leveraging the initial NSF support to a current total of just over US$ 3.5 million in external funding from North American, Scandinavian, and UK sources. NABO participants have gotten by with help from their friends and neighbors, and have been able to take on projects and address problems beyond the capability of any single scholar, university, or national research program.

Case Study: Early Settlement in N Iceland

While one objective of this paper is to indicate the general benefits (scholarly and financial) of sustained, active, and coordinated interdisciplinary international cooperation, the only real justification for involvement in the acronym-rich world of global change research is the improvement of our collective contribution though case-specific, problem focused field and laboratory research projects. The remainder of this paper turns to a presentation of the results of one of the largest and longest-lasting cooperative NABO projects, the "Landscapes of Settlement in NE Iceland" project (1996-present) in the inland Mývatn district (Mývatnssveit).

Iceland is a volcanic island situated atop the North Atlantic ridge. It is subject to frequent volcanic eruptions, many of which provide a widespread fallout of volcanic ash (tephra). Where identified, these tephra layers define isochronous marker horizons that can be traced through sediment, soil profiles and archaeological deposits (Thórarinsson, 1981; Dugmore et al., 2004). Southern Iceland is warmed by the North Atlantic drift and is classed as a boreal environment (with little persistent snow in lower elevations). Northern Iceland is significantly colder (low arctic, substantial long lasting winter snow), and the interior highlands are today covered by large glaciers and heavily eroded arctic deserts. Accounts of early settlement by Celtic Christian monks are still unproven by archaeology (but see Ahronson 2000), and archaeological evidence strongly indicates the first effective settlement of the island by humans occurred in the late 9th century AD (conveniently associated with the "Landnám" tephra layer now dated AD 871±2 by correlation to the Greenland Ice Sheet, Grönvold et al 1995). When Scandinavian settlers arrived, they encountered a mid Atlantic island with substantial arctic birch forest in the lower elevations, coastal sea mammal (including walrus) and sea bird colonies, migratory nesting birds, and the green grass that could feed their imported domestic livestock. The economy of the Viking Age North Atlantic settlers was flexible, but based around stock raising supplemented by limited barley growing and often extensive use of wild species (Dugmore et al 2005, McGovern, Perdikaris et al. 2001, McGovern, Perdikaris et al 2005; Simpson et al., 2002). Pasture was the ultimate source of wealth and power, and the correlation of cattle, good grazing, and chieftainship is clear in both the historical and archaeological record (Vésteinsson 1998; McGovern 2000, McGovern, Perdikaris et al. 2001). Between the initial settlement (Landnám), traditionally ca AD 874, and political union with Norway in 1262, Icelandic society was dominated by chieftains and great families, but constrained by codified laws and an elaborate system of traditional justice (Sigurðsson 1999; Vésteinsson 2000a). While today Iceland is an independent, vibrant, rapidly urbanizing modern Scandinavian nation of around 300,000, during the 15th-18th centuries Iceland was a relatively impoverished rural province in the kingdom of Norway/Denmark with a population fluctuating around 50,000.

Like many of the islands of Oceania and the Caribbean, Iceland thus represents an environment with a clear and relatively recent pre-human/human baseline, but Iceland would also become a fully literate island community whose natives were to produce some of the most important histories of early medieval Scandinavia and self-consciously antiquarian records of pre-christian pagan mythology. Iceland also has a long modern tradition of scholarship in both the natural and social sciences, particularly in history, anthropology, and the earth sciences. Icelandic medieval literature (sagas, hagiographies, histories, annals, law codes) provides a rich record of later landholding patterns, legal practice, stock raising, demography, conflict and competition, and invaluable access to an internal world view and emic social and economic categories that have been heavily exploited by anthropologists and social historians (Durrenberger 1989, 1991, 1992, Vasey 1991, 1996, 1997, 2001, Eggertsson 1998, Ogilvie 1997, Hastrup 1985, 1990, Byock 1990, 2001, Miller 1990, Ingimundarson & Ogilvie 1998, Vésteinsson 2000a). Particularly useful for economic history and settlement pattern analysis is a comprehensive land and stock register compiled 1703-12 (*Jarðabók*, Magnusson & Vidalin 1913-90) which still exists for most of Iceland and which has been recently converted to digital format (Edvardsson 2002). The Jarðabók entries provide farm- by -farm details of early 18th c stock raising and wild resource use, and retain some elements of medieval land valuation systems (Fridriksson et al 2004). However, until the 12th century, *none* of the medieval written sources are contemporary with the events they describe, and are problematic sources for the reconstruction of economy and society at Landnám. The first two centuries of Icelandic archaeology are effectively prehistoric and can only be directly investigated by archaeology and paleoecology (Vésteinsson 1998, 2000b).

Research problem – Unintended Human Impact on Island Ecosystems

Iceland has long been famous both for its rich medieval literature and for an extreme human impact on vegetation, soils, and landscapes since its settlement in the 9th century AD. While Icelanders were composing the prose and poetry that still comprise major sources of the history of the North Atlantic in the Viking Age and a key element in the literary heritage of medieval Europe, they were also participating in massive and often unanticipated alteration of their mid-Atlantic island. It is estimated that 90% of the forest and 40% of the soil present at the 9th c *Landnám* has disappeared, and 73% of the modern land surface is currently affected by soil erosion (Arnalds et al 1997). Scores of deflated Viking-age farm ruins now stranded in gravel deserts devoid of trees, grass, and soil bear witness to the complete destruction of the environment in some parts of the country. The growth of the modern Icelandic economy since 1900 was based largely on fishing rather than agriculture, and in many parts of Iceland today rural farming settlements continue to be endangered by soil erosion begun in the 10th century. The deliberate introduction of the NW European Iron age agricultural complex of domestic mammals and crops and the accidental introduction of a host of European insects and wild plants (Buckland et al 1991a & 1991b) rapidly transformed plant communities never previously subjected to grazing pressure by mammals and creating what Paul Buckland has called an “ovigenic landscape” (Buckland 2000). Rapid deforestation often closely followed first settlement (Hallsdóttir 1987, Caseldine et al 2004) and was in turn often followed by soil erosion beginning first at higher elevations and progressing downslope as groundcover was breached over wider and wider areas exposing the highly friable Icelandic *andisols* to wind and water transport (Dugmore & Buckland 1991, Dugmore & Erskine 1994).

The biogeography of the North Atlantic islands may have compounded the environmental assessment efforts of first settlers: essentially NW European plant communities extend from Norway and the British Isles all the way to southern Greenland (Buckland 2000, Dugmore et al 2005). A 9th century colonist coming from coastal Troms district in North Norway (north temperate climate despite its location above the arctic circle) who came hundreds of miles *south* to settle in Iceland might be excused for failing to immediately recognize that pasture plant communities familiar from home were in fact much closer to their biological range limits in Iceland and thus more vulnerable to grazing pressure. The volcanic andisols of Iceland are also subtly different from most soils of the settlers’ homelands, and are far more structurally vulnerable to wind and water transport (Arnalds 1990) and less responsive to fertilization. An “over-optimistic pioneer fringe" of 10th century settlement may have pushed into the interior highlands only to see vegetation and soils destroyed by the grazing pressure of their imported animals (Sveinbjarnardóttir 1992, but also Dugmore et al forthcoming b). Local populations of walrus in southwest Iceland documented by zooarchaeology also seem to have been killed off in the first few generations of settlement, and wild birds (described as initially "unwary" and easy to kill in later accounts) made up a major portion of animal bone collections (archaeofauna) in southern Iceland (Perdikaris & McGovern 2005, McGovern et al 2001, McGovern 1999, 2000, Vésteinsson et al 2002). Analysis of a suite of 8th-11th century archaeofauna indicated that colonists were importing a very standardized mix of domestic stock, imposing the same suite of cattle, pigs, goats, sheep, horses, dogs, and cats on every island settled (McGovern et al. 2001). This attempt to transplant a familiar economy to unsuitable ecosystems resulted in the (brief) attempt at pig keeping in Greenland in the 11th century, and substantial piggery lasted in Iceland throughout the 10th century (McGovern 1985, Olafsson et al 2005). By the time Iceland became a province of Norway in 1264 (following a prolonged civil war among its great magnate families), the country had become a very different place environmentally as well as socially from the Landnám age.

If the marginalization and relative poverty of the later medieval and early modern period had partly environmental roots, then it would appear that the early settlers' application of ultimately unsuitable models for land management had effectively passed on a crushing bill to their descendants through their early landuse decisions (Amorosi, Buckland et al 1997). What happened in the un-documented first two centuries of settlement in Iceland? Or perhaps more specifically; to what extent did the settlers adapt to their new environment, creating a sustainable economy for themselves, and to what extent did they continue practices developed in a different environment, thus reducing their capacity to produce riches and stability for their community?

"Traditional Narrative" of the Landnám Period (ca. 1990)

By the last decade of the 20th century, sustained multi-disciplinary (but mainly single site) investigations in Iceland had produced what may be termed a "traditional narrative" describing the process of Landnám and its environmental consequences (McGovern et al 1988 is a representative example).

- Settlement proceeded from coastal enclaves inland, probably following major river valleys in gradual expansion (perhaps sometimes too far) into the interior highlands as less wealthy or successful colonists were pushed out of the most desirable districts.

- First settlers had claimed vast tracts later subdivided among followers, but the individual independent farmer (*bondi*) and his farm household (so evident in the sagas) were the basic element of settlement and subsistence.

- Human impact on all wild resources was immediate and severe. “Natural capital” (in the sense of Cronon 1991) accumulated since glacial times was rapidly drawn down and expended to finance the rapid expansion of the initially limited numbers of imported domestic stock during the first years of Landnám.

- Deforestation was uniformly rapid; trees were cleared from all but a few belatedly protected areas.

- Almost all manufactured goods were imported, establishing a long term dependency on continental Europe for iron and other critical materials.

- Cognitive maladies (“false analogy”, “insufficient detail”, “short observational series”) prevented effective adaptation of NW European economic expectations to Icelandic realties.

- “Tragedy of the commons” (Feeny et al, 1990) had been played out in the highland pastures, leading to erosion rolling downslope and eventually overwhelming infields and farms.

- Climate cooling in the later Middle Ages impacted a landscape and society already riddled with self-created vulnerabilities and substantially expended natural capital reserves.

- Competition among elites interfered with effective environmental management, pushing tenants into unsustainable practices and eventually destabilizing whole regions.

This narrative certainly evokes parallels in many parts of the modern world, where over-grazing and land degradation affects up to 40% of the earth’s vegetated land surface (Brady & Weil 1999). The direct connection of these archaeologically visible processes to both modern Icelandic and global erosion control efforts was used to justify application for global change funding to supplement traditional sources of support for archaeology. Just over a decade later (thanks to this expanded funding), we now recognize that many aspects of the traditional Icelandic environmental Landnám narrative above are simply wrong, others are clearly oversimplifications, and that the model as a whole needs revision if it is to provide an effective tool for modern landscape managers. These realizations are not the result of gradual accumulation of facts derived from more single-site excavations, but of a sustained program of cross-disciplinary, landscape – scaled investigation made possible by the support of US, Icelandic, and UK global change research funding to what became the “Landscapes of Settlement” project.

Landscapes of Settlement in Northern Iceland

The Landscapes of Settlement project began as a single-site investigation centered on the site of Hofstaðir near Lake Mývatn in north eastern Iceland (Figure 1 location Map). Hofstaðir was identified as a potential pre-christian "temple" site in the 19th century, and was the site of one of the earliest fully professional archaeological excavations in Iceland in 1908 **(**Bruun & Jónsson 1909, 1910, 1911). Bruun and Jónsson's partial excavation revealed an exceptionally large long hall (floor area 270 sq meters while most Viking age halls varied between 60-90 sq meters) with associated middens whose well preserved bone collections generated the first professional zooarchaeological report for Iceland (Winge in Bruun & Jónsson 1909). The site was partially re-excavated by Olaf Olsen (1965) who identified it as one of a class of "temple farms"- sites that may have seen regular pagan ritual activity but were primarily working farms and elite residences rather than specialized structures like Christian churches or classical Greco-roman temples. In 1991, teams from the Icelandic Institute of Archaeology led by Adolf Friðriksson (and joined by Orri Vésteinsson in 1995) began what became a multi-year program of open area excavation (1996-2002) that eventually revealed a complex series of outbuildings and undamaged earlier floor layers, and recovered a large well preserved archaeofauna from stratified contexts dating from the 10th to early 11th centuries (Friðriksson 1993 et seq, Friðriksson et al 2004, Lucas 1998 et seq; Simpson et al., 1999). The collaborative investigations at Hofstaðir conclusively demonstrated that the site was indeed a working farm, where a full range of settlement age domestic animals were maintained, cooking fires generated ash and fire cracked stones in large quantities, and local bog iron was smithed regularly.

However, some finds and faunal patterning also suggest regular ritual activity. During excavation of the wall collapse and the terminal floor layers of the great hall and its outshot rooms 11 cattle skulls, one male pig, one male goat and one sheep skull were recovered, all showing depressed fractures between the eyes and marked differences in weathering between front and interior of the skull, suggesting that they had been displayed outside the building for some time before their eventual deposition (Figure 2 cattle skull). All the cattle and caprine skulls either had horn cores attached or were naturally hornless (a very rare trait in early medieval Nordic stock). Two of the cattle skulls were found face down in the wall collapse, and the rest of the skulls were tossed in a pit in one of the side rooms of the structure during demolition. As part of the demolition process, two sheep were beheaded and both heads and bodies thrown into the same room but were otherwise left un-butchered. Sheep heads were placed in each doorway as demolition was completed and the great hall was abandoned as the farmstead moved approximately 140 m to the southwest, next to a newly constructed Christian chapel (who's two basal radiocarbon dates fall around AD 1000). The cattle skulls are unusual in that three are definitely from mature bulls (in the 1712 Jarðabók register the entire Mývatn district had only two immature bulls among

18 occupied farms), and that horn cores were normally broken off skulls to extract the horn for craft work in specimens recovered from midden contexts. Also unusual is the age distribution of the female skulls with intact dentition- all are young adult animals around 2.5-3.5 years old (in the "prime beef" age). In most Icelandic archaeofauna from all periods there is a strong "dairy culling" profile, with a high percentage of newborn calves and old adults (presumably worn out milkers) dominating all skeletal and dental age indicators. At Hofstaðir, the midden deposits generally conform to this dairy age profile, but with an overlay of a small but regular addition of cattle also dying in the 2-4 year range. Sheep mortality patterns tend to be complicated by a mix of dairying, meat, and wool production strategies, but again Hofstaðir is unusual in the number of "prime meat age" specimens. While research is ongoing, current zooarchaeological evidence suggests that some regular event (in the early summer) regularly resulted in the death and consumption of cattle and sheep in their prime (thus not the culling off-take of the normal economy) and the beheading and display of the heads of some cattle and other domestic animals. These patterns are not typical of other Icelandic archaeofauna, and would tend to support Olsen's model for a "temple farm" combining normal farming activity with recurring seasonal rituals involving the sacrifice, consumption, and display of major domestic animals whose death would have been expensive in terms of the normal economic cycle as we understand it. However, apart from the size of the structure, there is no good evidence for permanent elite residence at Hofstaðir, leading to the suggestion that the residents were caretakers of a communal feasting hall (Lucas, forthcoming).

While the excavation program at Hofstaðir progressed, survey teams documented early sites around the lake, eventually documenting over 1,200 sites and structures in the Mývatn region (Mývatnssveit). As test pits and surface collections revealed excellent organic preservation at an increasing number of sites datable to the 9^{th}-12^{th} centuries in Mývatnssveit, we somewhat belatedly realized that this inland region was particularly well suited to a sustained landscape-scale multidisciplinary investigation. Major excavations (Figure 2) have taken place at Sveigakot (1999-2006), Hrísheimar (2001, 2003-06), Steinbogi (2002), and Selhagi (2001) and mapping and small scale excavation has been carried out at abandoned farm sites at Oddastaðir, Brenna, Stong, (Vésteinsson 2001b, Vésteinsson ed. 2002 et seq; Edvardsson 2004).

Following a thorough revision of the entire Icelandic corpus of grave-goods (Eldjárn and Fridriksson 2000), the Mývatn pre-christian burial sites as well as all (19) such sites in NE-Iceland have been revisited (Friðriksson 2004b) offering new insights into the development of the Landnám society (Friðriksson 2004a). New studies of burial topography have led to fresh burial finds at Hrísheimar (Friðriksson and McGovern 2005), Daðastaðir (Friðriksson *et al* 2005a), Litlu-Núpar (Friðriksson *et al* 2005b) and Saltvík (Friðriksson *et al* 2005c), from which both artifacts and human and animal bones have been recovered and are now forming a new basis for the chronology of the whole region (see below).

Archaeological and paleoecological investigation in Mývatnssveit has been greatly aided by close cooperation with the long-established Mývatn Research Station (affiliated to the Icelandic Ministry for the Environment), which generously provided comparative zoological specimens, steadily expanding low-level air photo coverage, and a trove of local environmental and cultural information and contacts. Collaboration with geophysicists, geoarchaeologists and tephrochronologists from Iceland and the UK also revealed a complex Holocene environmental history of the region and the presence of a series of datable tephra (notably the Landnám sequence of AD 871±2, a 10th century Veiðivötn layer, Hekla 1104, and 1300, Katla 1262, Veiðivötn 1477 and 1717). Our research combined with that of Larsen *et al*. (2002) has built up an excellent tephrochronological framework which can be used to help answer chronological questions, as well as rates of environmental change.

Mývatnssveit Region

The Mývatn region (Mývatnssveit) straddles the Mid-Atlantic rift, and has been volcanically active for thousands of years (Figure 1). The broad shallow lake is fed by underground channels that drain a large area of basaltic lava fields and sand deposits. The groundwater feeding the lake through a number of springs gushing forth along its east shore is rich in phosphate and silica leading to a luxuriant growth of diatoms and Cyanobacteria (blue-green algae) that support the populations of Chironomid and Simuliid flies that provide its name ("*midge lake*"). The lake is renowned for rich fishing, mainly arctic charr (*Salvelinus alpinus*). Despite its altitude of 250-300 m a.s.l. the Mývatn district supports rich hay fields around the lakeshore. Today, the highlands around the lake to both the North and South are heavily eroded deserts and Mývatnssveit represents the largest surviving inland farming community in northern Iceland. The major drainage is the Laxá river flowing northwards to the sea approximately 60 km away. The Laxá ("salmon river") is a famous trout stream (*Salmo trutta*) and in its lower reaches also receives migratory Atlantic salmon (*Salmo salar*), which do not reach the lake area. The Laxá is joined by the Kráká River which extends southwards into the interior highlands, today largely stripped of vegetation and subject to ongoing soil erosion. Many smaller, but less fertile lakes surround Mývatn, also providing habitat for charr and trout. Mývatn hosts vast numbers of migratory waterfowl in spring and summer, with currently over 15,000 breeding pairs nesting around the lake. High quality wet-meadow was available around the lake, particularly around Reykjahlíð in the northeast corner of the lake (prior to an 18th c lava flow), and in a broad periodically flooded marshland with small ponds and streams called *Framengjar,* a delta created by the Kráká river. Since at least the 18th century, the Kráká has been a destabilized, biologically impoverished, silt laden wandering stream, annually transporting tons of sand from the rapidly eroding southern highlands and infilling much of the southern portion of the Framengjar.

When the 9th century settlers arrived in this interior highland lake basin, they found a somewhat different environment. The hills around the lake were covered with a mixed vegetation of birch woods, heath, grassland and wetlands. Stands of birch woods probably extended up to at least 400 meters, except for the wet-meadows around the lakeside and the Framengjar (Olafsdóttir et al. 2001). At higher elevations to the north and south of the lake, the forest probably thinned out into dwarf-shrub heath lands and arctic-alpine herbaceous vegetation above 400-500 m, with some copses potentially extending up to 600 m in elevation.

Geoarchaeological trenches indicate that at least 1.5 meters of redeposited silts now cover the late 9th century land surface along the southern edge of the surviving Framengjar wetlands. Distribution of waterfowl and freshwater fish bones in 9th-10th c midden deposits along the Kráká also suggest that the productive ponds, streams, and wet meadows of the Framengjar were once broader and extended further south along the now heavily eroded banks of the Kráká river (McGovern, Perdikaris et al. 2005). Pollen evidence from a core taken from Lake Helluvaðstjorn, 5 km southwest of Mývatn (Fig. 3), suggests that birch woodland was not immediately cleared from the whole region at first settlement, but instead persisted for several centuries (Lawson et al. in prep.). Large fragments of burnt wood (including some cross-sections of carbonized birch trunks probably originally ca 10 cm in diameter) have been recovered from site midden deposits dating from the mid-10th to later 11th centuries, suggesting that wood lots were still producing fairly substantial trees over a century after first settlement. After the 12th century, such large pieces of charcoal become rare. At the site of Sveigakot (at 286 m asl) on the southeastern margin of the Framengjar, a pattern of tree root casts appearing beneath both the 9th c Landnám tephra sequence and a midden deposit associated with an early farm site indicated the presence of a fairly dense wood, with trunk spacing ca 50-75 cm apart. By the time a second tephra fell in the early-mid 10th century, the trees were gone and the ash covered a leveled midden surface. Human impact had begun in the Mývatn lake basin.

Chronology and Settlement in Mývatnssveit

A growing suite of AMS radiocarbon dates (most on collagen from cattle or pig bones) provide a framework for phasing sites and contexts, especially where the local tephra sequence obviates some of the inherent problems of the 10th century radiocarbon calibration plateau (Figure 3, radiocarbon calib). One immediate surprise was the early date for settlement in Mývatn. We have encountered definite midden deposits (including imported domesticates) in direct contact with the late 9th c Landnám tephra sequence at Sveigakot, Hrísheimar, Selhagi and probably Brenna (Vésteinsson ed. 2002, see Figure 1). Part of the research program has been the radiocarbon dating (and isotopic analysis) of previously excavated pre-christian burials in the region and the selective excavation of additional graves (Friðriksson 2000, Friðriksson 2004 ed., *et seq.*). As many pagan graves included horse and/or dog skeletons, these domesticates can provide a chronological control even when the human remains produce partly maritime carbon isotope ratios likely to generate “old” dates. As figure 3 and Table 1 illustrate, the horse bones (wholly in the terrestrial food web) that are associated with Mývatnssveit burials, produce radiocarbon ages that indicate human occupation of this inland zone in the 9th century. Our old model of a gradual penetration inland by individual households from the coastal zone driven mainly by population pressure now looks decidedly unlikely, and we need to consider other approaches to understanding the Icelandic settlement process.

Political Ecology and Settlement Process

Basal radiocarbon dates from the Greenlandic colony (settled from Iceland in the late 10th-early 11th centuries) also indicate surprisingly early occupation of what appear to have always been small, marginal farms in highland valleys or on steep slopes with poor pasture (Arneborg 2000). As in Iceland, the radiocarbon evidence does not support the idea of a very gradual expansion from a few coastal centers, but indicates instead a very swift dispersal within the first generation of settlement. Vésteinsson et al (2002) discuss these two unexpected patterns for Landnám, suggesting that significant simple population pressure was very unlikely to have produced such early dispersal or such strong resource competition that independent settlers were immediately driven into marginal areas given the small initial colonizing population. An alternate hypothesis can be drawn from the Icelandic saga accounts of early settlement, particularly the often cited passage from *Egils saga* describing the establishment of the settlement of the chieftain Skallagrim in Borgarfjörður in SW Iceland:

*"Skallagrim was an industrious man. He always kept **many men with him** and gathered all the resources that were available for subsistence, since at first they had **little in the way of livestock** to support such a **large number of people**. Such livestock as there was **grazed free in the woodland all year round**. ...there was no lack of driftwood west of Myrar. He had a farmstead built on Alftanes and ran another farm there, and rowed out from it to **catch fish** and **cull seals** and **gather eggs**, all of which were there in **great abundance**. There was plenty of **driftwood** to take back to his farm. **Whales beached** there, too, in great numbers, and there was wildlife there for the taking at this hunting post: the animals were **not used to man** and would never flee. He owned a third farm by the sea on the western part of Myrar. ... and he planted crops there and named it Akrar (Fields). ... Skallagrim also sent his men upriver to catch salmon. He put Odd the hermit by Gljufura to take care of the **salmon fishery** there ... When Skallagrim's livestock grew in number, it was allowed to roam mountain pastures for the whole summer. Noticing how much better and fatter the animals were that ranged on the heath, and also that the sheep which could not be brought down for winter survived in the mountain valleys, he had a **farmstead built up on the mountain**, and ran a farm there where his sheep were kept. ... In this way, Skallagrim put his livelihood **on many footings**." (*Egil's saga, ch. 29. Transl. in Hreinsson ed. 1997, *The Complete Sagas of Icelanders. Including 49 Tales*, vol. 1, 66 (emphasis added).

This image of such a "Skallagrim effect" of chiefly first settlers claiming huge areas and "putting their livelihoods on many footings" by scattering retainers widely into different resource zones recurs in other written accounts, including the apparently comprehensive Landnámabók (Book of the Settlements, Benediktsson ed. 1968). While such accounts provide a mechanism for the rapid, wide dispersal of small sites over a large area (perhaps initially occupied seasonally or by a very few individuals), it does not adequately explain the pattern of early tephra and radiocarbon dates for both farms and pre-christian burials in 9th-early 10th century Mývatnssveit. These are not the isolated dwellings of salmon-fishing hermits, but fully established farms with resident lineages wealthy enough to fund elaborate burials of their ranking members. In addition, we have some reasons to distrust all the literary accounts of the Landnám period. They were all written down 250-300 years after the events described, and modern source criticism has identified many cases of both deliberate political manipulation and ad *hoc* filling of gaps by speculative use of then surviving place name evidence (see Friðriksson & Vésteinsson 2003 for discussion). While chiefly management of settlement and the settlement pattern was certainly a major factor in Landnám, it probably did not operate exactly as recorded by later scribes.

Vésteinsson (1998, 2000b) has suggested an alternate framework combining social and environmental variables. Given that the densely forested valleys may have been initially unattractive settlement choices compared to wet meadows or existing grass/sedge communities, early settlers may have leapfrogged the valleys in search of farm sites with more immediately available pastures. The higher elevations at the edge of what was then broad upland meadow would have been an attractive settlement zone targeted early by the wealthy and powerful rather than unattractive margins left to under-financed, overoptimistic fringe settlers (see Thórarinsson 1944, Smith 1995). Mývatnssveit may have represented a particularly attractive higher altitude location, with its uniquely productive lake ecology. As the valley bottoms became gradually deforested and pasture replaced the dense woodlands of Landnám, the locational advantages would have shifted, promoting patterns of elite farm distribution more familiar from the medieval records. Air photo analysis combined with field survey and selected excavation has documented a very extensive system of boundary dykes which appear to have acted to divide individual holdings and possibly demarcate boundaries of common grazing (Einarsson et al 2002). Tephra layers indicate that most of these dykes (many 2-3 m thick and running for kilometers) were constructed in the 11th-12th centuries as part of a very labor intensive program of physical demarcation of cultural landscape. Some of these dykes follow later medieval property or administrative boundaries, but others do not, suggesting changes in the political and economic landscape since their creation. As the natural environment changed and the population of humans and their domestic animals increased, the cultural landscape also adjusted, with the politically powerful certainly striving to amass resources and followers, but it is difficult to detect the presence of a single dominant chieftain of the Skallagrim sort.

In Mývatnssveit, the 18th century *Jarðabók* and earlier medieval documents indicate a more complex division of power, with an early chieftain's settlement at Reykjahlíð near the wet meadows of the northeast corner of the lake, while two potential competitors at Grænavatn and Skútustaðir were spaced around the edges of the Framengjar wetlands along the south shore (Friðriksson et al.

2004). A 13th century saga partially set in Mývatnssveit recounts multiple homicides and repeated, eventually successful attempts to assassinate "Killer Skúta" (the supposed founder of Skútustaðir), but it is unclear how much of the tale relates to 9th-10th c competition and how much to more contemporary later medieval power struggles (Hreinsson ed. 1997). Hofstaðir would make sense as another early chieftain's farm, but tephra running beneath the walls of the great hall make clear that this farm was in fact settled in the mid- to-late 10th century rather than in the first wave of Landnám (Lucas 2005). The great hall was probably in use for less than a century before being demolished and abandoned in the 11th century. The "temple farm" at Hofstaðir thus appears to be an ultimately failed ploy by a second or third generation chieftain to set himself up in competition with the existing power centers at Reykjahlíð, Grænavatn, and Skútustaðir, all of which had access to better quality agricultural land. Well furnished pre-christian burials (some with associated weapons and other valuables) and scattered finds of Viking age luxuries such as amber beads, a copper alloy sword chape (Hrísheimar) and ring headed pin and silver pendant (Hofstaðir) from floor and midden suggest a comfortable level of prosperity on many of the early settlement farms. When earlier patterns of chiefly competition were consolidated by the formation of the parish structure in the 12th century (Vésteinsson 2000), both Reykjahlíð and Skútustaðir signaled their triumph by erecting parish churches. However, the 12th c parish boundaries were gerrymandered to place both Hofstaðir and Graenavatn in the more distant parish of Reykjahlíð instead of the far closer and more convenient (but then bitterly rival) church farm at Skútustaðir (Figure 1).

Political power in Mývatnssveit seems to have been fairly fragmented from first settlement, with no local paramount chieftain capable of dominating the entire basin emerging. It is difficult to model over-centralized or detached chiefly decision- making as a cause for adverse early environmental impact. Current evidence instead suggests at least two or three early chiefly aspirants, probably surrounded by lesser farmers initially capable of playing off competing chieftains against each other (Miller 1990). By the 13th century, Mývatnssveit had become a political backwater marginal to the violent power struggles of the great magnate families based elsewhere. The 18th century Jarðabók record shows far less concentration of wealth and stock on a few farms than is visible in nearby districts, and little apparent variation in household subsistence strategy. While the district was later known as a refuge during famines (because of its freshwater fishing), and a major source of mined sulfur (for gunpowder and medicinal production) it remained economically marginal until the expansion of tourism and industry in the later 20th century brought a resurgence of prosperity probably not seen since the 10th century.

Iron Production and Charcoal Making

Air photos have revealed patterns of circular depressions along ridgelines in several parts of Mývatnssveit and the surrounding valleys. Excavation indicates that these are charcoal production pits similar to those documented in southern

Iceland (Dugmore et al in press b) and their density and extent suggests a fairly intensive production that could not be sustained by the few modern stands of surviving birch woods. Detailed archaeobotanical, radiocarbon and tephra analysis is ongoing from the excavated pits but preliminary results indicate that the charcoal largely consisted of locally grown birch branch wood cut in late spring / early summer that may indicate some form of deliberate management of the resource. All of the pits investigated were used prior to the fall of V1477 that filled the pits. Recent excavations at Hrísheimar have uncovered evidence of very large scale iron smelting in the form of a group of smelters and smithy structures clustered on a ridgeline just above the farm ruin and quantities of production slag and bloomery debris have been recovered from the eroded ridgeline (Edvardsson 2004). The charcoal produced in the pits was very similar in form to the material recovered from the middens at Hrísheimar, suggesting the smelting at the site used locally produced charcoal. Therefore, it would appear that this now-abandoned Kráká valley farm, was heavily involved in iron production and was a major consumer of wood charcoal. Excavations continue at Hrísheimar, but it would appear that one product of Landnám-era Mývatnssveit may have been smelted iron. While the impact of charcoal making on the birch woods would have been significant, a local iron production industry might also provide incentive to efforts at woodland management, perhaps in turn reflected in the pollen profile of persisting birch woods on now barren hillsides at Helluvaðstjörn. In any case, early Iceland was clearly far less dependent upon imported iron than it was to become in early modern times, when virtually all metal tools were imported.

Pastures, Soil, and Farming Strategies

Analysis of regional Mývatnssveit Holocene geomorphology based on multiple soil cores tied together by tephra isochrones indicates that the highlands around the lake basin have undergone repeated phases of vegetation and soil loss and re-stabilization since deglaciation, suggesting the instability of the region over the long term (Olafsdóttir & Guðmundsson 2002). Following periods of increased sediment accumulation, c 5000 BP and c 2500 BP that Olafsdóttir & Guðmundsson (2002) relate to enhanced regional erosion Mývatnssveit seems to have entered a period of stabilization prior to human settlement. It is possible that in pre-Landnám times the aeolian sediment accumulation forming the regions' soil was significantly affected by rates of tephra production. Volcanic ash is a major component of the Icelandic andisols, and in prehistoric times when sediment accumulation rates were generally lower than in the last 500 years, the proportion that was derived from reworked tephra falling in the interior barren-lands could have been significantly higher. It is notable that the basal ages of soils in the Mývatnssveit region becomes younger into the interior, a pattern consistent with soils cover extending inland as more and more tephra is deposited in the highlands and reworked down slope to aid soil profile formation. Crucial changes occur with settlement. Generally across Iceland aeolian sediment accumulation rates increase, a change that Thórarinsson (1961) convincingly argued to be a result of soil erosion. Many studies have since reinforced this picture (eg. Dugmore et al., 2000), suggesting a widespread shift in environmental processes as a result of human impacts; more sediment on the move as a result of the widespread development of erosion patches in vegetated areas, and as a result greater rates of accumulation in the reducing areas of surviving vegetation and soil cover.

In contrast to areas of southern Iceland (eg Dugmore and Buckland 1991, Dugmore et al., 2000) geomorphological and tephrochronological studies in the vicinity of the archaeological sites along the Kráká (Sveigakot and Hrísheimar) indicate a comparatively limited increase in aeolian sediment accumulation following the Norse settlement of the area. In general, there appears to be a relatively slow increase in regional soil erosion through the Middle Ages, and, with the exception of some localized episodes of soil erosion prior to 1477, it seems that it was not until after the deposition of the Veiðivötn 1717 tephra layer that key local thresholds were crossed. The 18th century record is characterized by greatly increased accumulation rates (up to 20 times the 1477-1717 rate in some profiles) and the presence of repeated sand layers in the profiles, a feature not present in the older and pre-Landnám soils (Newton *et al*., in prep). In general, therefore, the soil profiles in the area, do not suggest that Landnám immediately triggered widespread erosion on the regional scale in the Mývatnssveit, and that the catastrophic levels of deflation and erosion visible in the modern landscape post-date AD1700 (see also Einarsson et al 1988).

Within this broad picture, there is much variability in soil erosion impact on the scale of the individual farm holding, and investigations focused on this scale produce evidence of variability in land management between farms. When set in the regional context of Olafsdóttir & Guðmundsson (2002) detailed investigation of accumulation patterns in grazing estates associated with the contrasting early settlements at Hofstaðir and Sveigakot indicate marked differences in human impacts (Simpson et al., 2004). In both locations there is evidence of an acceleration of soil erosion with settlement through to ca. A.D. 1477. However, at Hofstaðir there was a subsequent reduction in erosion rates to substantially below the regional average, while at Sveigakot the acceleration of erosion that began with settlement continued, leaving the area as sub-arctic desert. Part of the explanation for these differences in settlement impacts is in inherent landscape sensitivities - pre-settlement erosion patterns indicate a greater rate of sediment movement at Sveigakot compared to Hofstaðir – but positive land management strategies were also of significance at Hofstaðir. Here, on a continuously occupied farm site, the later reduction in land degradation to substantially below the regional average indicates a household community that was managing livestock grazing to minimize negative land degradation impacts.

In contrast to areas of southern Iceland (eg Dugmore and Buckland 1991) Suggestions of early land management within the Hofstaðir estate is not confined to grazing livestock, there is also evidence of fuel resources regulation and management (Simpson et al., 2003; Vésteinsson & Simpson 2004).

Micromorphological and image based analyses of fuel residues found in midden stratigraphies indicates that fuel resources included peat, mineral based turf and birch wood, but with temporal trends in utilization mix. Residues from low temperature – domestic combustion of mineral-based turf are evident throughout midden stratigraphies, although more concentrated in earlier phases. In contrast, peat utilization is almost entirely associated with high – 'industrial '- temperature combustion and evident throughout the stratigraphy, while wood ash residues from low and high temperature combustion become more prevalent in later phases of midden stratigraphies. This latter observation hints that woodland management may have promoted different age structures and densities of woodland, raising productivity for a time.

Although Hofstaðir and Sveigakot are less than 12 km apart, their trajectories of human-stock-vegetation-soil interactions were critically different. The eventual outcomes for the farm households were also different. Hofstaðir is still farmed, and was continuously occupied despite some shifts of the dwelling around its homefield. Sveigakot was settled earlier, initially by people living in a series of sunken featured buildings, which were replaced by a small hall around 60 square meters in floor area in the late 10th century. After some decades it was briefly abandoned, and when re-occupied in the late 11th century its hall floor area was shortened to ca. 35 square meters and the associated archaeofauna shows changes (emphasizing wool production) which may be associated with declining status or tenantry. The site was completely abandoned by the early 13th century, and was only rediscovered by archaeological survey in 1998 as bone and charcoal eroded out of deflating middens surrounded by a denuded rock-field (Vésteinsson 2001b). The continuity of farm management strategy may have been an important factor in preserving the productivity of pasture communities around Hofstaðir, and the changing economic and social fortunes of Sveigakot's household certainly was a factor in the decline and eventual destruction of pastures and soil around the farm. In early Iceland, as in so many areas today, human poverty and powerlessness are bad for pastures as well as people.

We now know that animal management strategy did not remain static throughout the period of settlement. Archaeofauna from Hrísheimar, Sveigakot, Hofstaðir, and Selhagi clearly indicate that early settlers of Mývatnssveit did indeed introduce the standard Landnám complex of cattle, sheep, goats, horses, and pigs whose combined grazing, browsing and rooting would certainly be effective in deforestation and (if unchecked) could lead to soil exposure and erosion. However, this initial mix of domesticates was altered during the 10th century, as goats became increasingly rare and pigs were progressively removed from the farmyard, eventually becoming extinct in Iceland (figure 7). As the early 13th c archaeofauna from Steinbogi indicates, there was also a shift away from cattle production towards the sheep-dominated pattern of the 18th c Jarðabók farms (figure 8). While the early settlers certainly initially introduced a traditional mix of domestic stock familiar from their homelands, they were by no means passive hyper-conservative "prisoners of culture" (Descola & Palsson 1996) incapable of altering their farming strategy as they gained local experience and as local woodlands (which made pig and goat keeping inexpensive) shrank.

Surviving law codes post-date the Landnám period by centuries, but contain a wealth of landuse and stocking legislation clearly shaped by practical experience and extensive case-by-case litigation built up over years. *Grágás* (surviving in late 13th century manuscripts; Dennis et al. 1993) makes clear that pigs were by then viewed mainly as "problem animals" likely to generate disputes rather than economic mainstays, and detailed land management provisions make equally clear that access and use of common pasturage was by no means open or unregulated. As Simpson et al. (2001) note; "regulatory mechanisms were in place to prevent overgrazing from at least the 1200s AD, with sufficient biomass to support the numbers of domestic livestock indicated from historic sources". While some aspects of the surviving law codes penalize under-use of pasture vegetation, the overall effect of the laws (if enforced) would be to closely regulate grazing pressure on common pool resource pastures.

Environmental simulation modeling predicting spatial and temporal patterns of vegetation biomass production and utilization (*Búmodel*: Thomson and Simpson in press), has been used to compare landscapes of the Landnám and Jarðabók periods (Simpson et al., 2001; Thomson and Simpson, 2005). Observations derived from this approach suggest that there were spatial and temporal variations in productivity within and between historic grazing areas and indicate that land degradation was not an inevitable consequence of the livestock introduced with settlement. The model also clearly indicates that utilizable plant biomass productions in winter and summer grazing area far exceeded potential grazing pressure, even when stock numbers were inflated beyond those indicated by archaeology or the Jarðabók record. The critical variable appears to be not total stock numbers, but the timing of the annual removal of flocks in autumn. If animals are allowed to graze even a week beyond the end of grass growth, pasture degradation sets in, leading eventually to breaching of the soil cover and rapid erosion. Correct assessment of the climatically driven onset of winter in the highlands thus appears to have been at least as important as management of total stocking levels.

Complicating Climate Instability

Until recently, most paleoclimatic data sets had resolution on the order of centuries or millennia, which led to simplistic or deterministic attempts to correlate climate and culture (Grove 1988, McGovern 1991). A major accomplishment of modern climatology has been the development of multiple climatic proxy indicators whose resolution is on the "human scale" of decades, years, or seasons (Jones and Mann 2004, Meeker & Mayewski 2002). In the North Atlantic context this most notably includes the Greenland Ice Sheet cores. The ice core data requires careful and informed interpretation, but can be used to document proxy temperatures on the seasonal scale, transforming the debate over climate impact in the extinction of the Norse Greenlanders (Buckland et al 1996, Barlow et al 1997). The new high-resolution proxy indicators are not restricted to isotopic temperature reconstruction but also provide geochemical indicators of sea ice extent and storminess, which suggest that the North Atlantic of the Viking age was relatively calm and ice free compared to conditions after the 15th c (Dawson et al. 2003).

These multiple high-resolution indicators permit better investigation of key questions as to which aspects of climate change are potentially significant in terms of potential impacts on people. One view is that a year of extremely bad weather (resulting in poor fodder crops, or high neonatal fatalities in domesticated livestock) could create issues for some (the poorest and most marginalized settlements), but a *sequence* of poor weather and repeated losses and poor yields is more likely to create significant problems for many, especially those in marginal environmental or cultural settings (eg Parry, 1978). Simple economic response models (*Farmpact*, McGovern et al 1988, McGovern 1992) developed for North Atlantic farming economies heavily dependent upon stock herding and pasture productivity have indicated that even very extreme events would have been less systemically damaging than a closely spaced series of less extreme, moderately poor growing seasons (Barlow et al. 1997). Sequence and spacing of climate events thus probably mattered more in terms of actual climate impact on North Atlantic medieval economies than did extreme cold spikes.

Perhaps an even more important factor in creating climatic economic impact could be one of *predictability*. Northern societies tend to be well-buffered against a wide range of climate fluctuation, and demographic records for early modern Iceland reveal considerable resilience and success in containing human mortality even in the face of combined cold weather and volcanic eruption (Vasey 1997.1997). Effective responses to bad seasons and even to strings of bad seasons were certainly within the competence of the traditional knowledge systems of the Viking Age Icelanders, and awareness of climatic variability is evident in the medieval law codes and annals (Ogilvie & McGovern 2000). However, the effectiveness of any climate response strategy depends on an ability to reasonably anticipate and predict the behavior of key environmental variables within a tolerable range (such as the end of the growing season in upland pastures), so that key renewable resources are not degraded beyond recovery. Climatic thresholds are famously hard to detect until crossed, and increasing inter-annual *variability* continues to adversely affect our own ability to effectively respond to rapid climate change in the modern circumpolar north. Increasing variability and declining predictability of climate/ environment/ resource interactions definitely stress local resource management strategies of northern peoples today, in some cases creating a frightening sense of devaluation of long held traditional knowledge bases (ACIA 2004). Similar problems in separating signal from noise certainly afflicted medieval communities, and declining predictability must be a key explanation for increased environmental degradation in the generally unstable conditions of the so-called

'Little Ice Age' of the later Middle Ages (Simpson et al., 2001).

A novel way to identify *predictably* in the GISP2 proxy records is through the use of a cumulative assessment of annual deviations from the long term mean (Dugmore et al *forthcoming*). Cumulative measures are generally not used in the analysis of time series of climate data because they add data from one year to the next rather than leaving each season as an independent event. The advantage of a cumulative approach when considering human dimensions is the 'memory effect' it simulates; a trajectory indicates change that is potentially predictable, a 'turn over' point highlights a time when the established pattern of the past change is no accurate guide to future trends. In addition steeper parts of the graph indicate extreme events and /or rapid change (Fig 5). Several key patterns emerge from cumulative assessments of the GISP2 data sets. Some highlight the onset of changes in the later Middle Ages with fundamental climate shifts in the early –mid 15th century and the extremes of the early 16th century. Others pick out earlier and potentially significant changes 975-1040 AD, and highlight the nadirs of the 18th century (probably linked to the massive erosion visible after the 1717 ash fall). For the farmers of Mývatnssveit, the increase in short term variability of the 10th-11th centuries would have been coupled with progressive deforestation, cultural landscape remodeling (probably involving intensive competition among elites), the introduction of Christianity, and a shift in stock raising strategy away from pigs, goats, and cattle, and towards sheep. In this context, it may not be surprising that some medieval land managers got the critical timing wrong for bringing down flocks from uplands or failed to optimally manage winter grazing in the lowlands.

Sustainable Egg Harvesting

Duck egg harvesting from the nesting grounds around Mývatn is first mentioned in the 1712 Jarðabók entry. The present rule to leave at least 4-5 eggs in the nest for the female to incubate is first mentioned by a traveler in the area in 1862 (Shepherd 1867), but self-imposed restrictions to harvesting are mentioned some 40 years earlier (Thienemann 1827). The 4-5 egg rule ensures a sustainable yield, as the ducks produce only 0.3-2.8 young per female a year on the average and the overall production of young is regulated by the availability of food in the lake, mainly midges and their larvae and small crustaceans (Gardarsson and Einarsson 1997, 2002, 2004). Today adult waterfowl are still not hunted, but the lakeside farmers collect an average of 10,000 eggs each spring. The zooarchaeological record for 9th-11th c Mývatnssveit indicates that birds were a minor part of the economy, and what bird hunting there was focused in every case upon the non-migratory ptarmigan (grouse, *Lagopus mutus*), even at Selhagi in the heart of the waterfowl nesting area. By contrast, the 9th-13th c midden layers at Hrísheimar, Selhagi, Brenna, Hofstaðir, and Steinbogi are rich in bird egg shell, with thousands of fragments recovered from some contexts. Microscopic analysis indicates that the majority of these fragments are from duck eggs, but ptarmigan and sea bird egg shells were also present (Sidell in

McGovern, Perdikaris et al 2005). These archaeological data indicate that the successful community management of waterfowl for sustainable egg collection is well over a millennium old. This example of genuinely long term sustainable wild resource use again conflicts with notions of the inevitability of human draw-down of natural capital following first settlement.

Coastal Connections– Scales of Integration of the Landnám Community.

One surprise in the archaeofauna from inland Mývatnssveit has been the presence of marine species 50-60 km from the nearest salt water. Seal bones have been found at Hofstaðir and Sveigakot, and a segment of porpoise tail (with butchery marks) was recovered from the late 9th century basal layers at Sveigakot. Sea bird bones and sea bird egg shell have been recovered from Selhagi, Sveigakot, and Hofstaðir, and tiny mussel shells probably transported attached to seaweed root balls are present in all the Mývatnssveit archaeofauna (McGovern, Perdikaris et al 2005).

However, fish are the most common wild taxa in these inland archaeofauna (Figure 7, major taxa). Unsurprisingly, locally available freshwater salmon-family fish (arctic charr and brown trout) make up the great majority of the identified specimens. Fluctuation in the relative abundance of charr and trout in these collections probably relate to complex interactions of local and regional patterns of erosion and deforestation, alteration of stream-side and lakeside ecology, changing lake nutrient cycling patterns, and climate change. A summary of the recent and paleoecological evidence for changes in freshwater fish ecology in Mývatnssveit appears in Lawson et al (2005), and a cooperative project on long term biological change in isolated Icelandic salmonid populations is now underway. As in other areas, zooarchaeological data have proven useful for modern biological conservation efforts (Lauwerier & Plug 2004).

However, bones of marine _cod- family fish (gadid) make up 12-30% of the identifiable fish from the fully quantifiable collections, and their presence in Mývatnssveit clearly relates more to cultural than to natural patterns (McGovern, Perdikaris et al 2005). While the locally available trout and charr are represented by the bones of the whole skeleton, the marine fish have a skeletal element distribution strongly indicating the transport of a prepared fish product. Figure 8 illustrates the bones found on the inland sites relative to the complete fish skeleton. Heads and mid-body vertebrae are conspicuously absent. The bones around the gill opening (especially the dense cleithrum) tend to be left in most dried fish products to keep the filleted upper body together and to aid in spreading the body cavity for drying. This bone element distribution suggests that the Viking age preserved fish was a flat-dried product (similar to modern Norwegian *klipfisk*) rather than the round-dried *stockfish* typical of the later fully commercial international fishery of the 11th-19th centuries. High species diversity within the gadid family is evident in these 9th-11th c inland archaeofauna, including haddock, saithe and ling as well as the Atlantic cod which come to dominate the later medieval-early modern international trade (Amundsen, Perdikaris et al 2005, Perdikaris & McGovern 2005). Similar patterns are visible in Iron Age North Norwegian fisheries, where elites managed an extensive production and local exchange of air-dried fish dating back to the 5th century AD (Perdikaris 1999).

In line with the occurrence of freshwater fish, marine mammals and marine fish in archaeofauna generally dominated by domestic mammals, the $d^{13}C$ results (–18.9 to –19.7‰), derived from the analyses of human bone collagen from the inland Mývatnssveit pre-Christian burials, indicate a small enrichment over values that would be typical of a wholly terrestrial diet in northern hemisphere, high latitude populations and would tend to indicate some reliance on aquatic resources. Arneborg *et al.* (1999) suggest for population groups from high northern latitudes that a $d^{13}C$ end member of –21.0‰ would be appropriate for 100% terrestrial diet while –12.5‰ would represent the end member for 100% marine diet. Detailed information on the effect of freshwater fish consumption on human bone collagen $d^{13}C$ values is not well documented. Cook *et al*. (2002) have demonstrated a similar range of $d^{13}C$ values (-18.2 to –19.5‰) for consumption of significant freshwater resources at Schela Cladovei in the Iron Gates Gorge of the River Danube during the Mesolithic. However, these small shifts in $d^{13}C$ were accompanied by significantly greater shifts in $d^{15}N$ (range = +13.2 to +15.3‰ cf. approximately +8‰ for a totally terrestrial diet). The Mývatnssveit $d^{15}N$ values were lower in range (+7.7 to +10.0‰), however, the shift would depend on the species consumed and its trophic level in the freshwater food web. Because of the mix of freshwater and marine aquatic resources at Mývatnssveit, it may not possible to adopt the strategy of Arneborg *et al.* (1999) to determine the marine ^{14}C reservoir correction in individual humans, based on the $d^{13}C$ results. Furthermore, without evidence to the contrary, we cannot rule out the possibility of a freshwater reservoir effect (Cook *et al.* 2001). The age offset between the humans and associated horse burials certainly indicate that a reservoir effect does exist. More work is currently under way on the chronology and isotopic dietary reconstruction of Icelandic pre-Christian burials, but at present these data appear to provide confirmation of the role of aquatic products in the diet of inland farmers during the settlement age.

Despite fully- established farming and extensive use of local freshwater fish and well-managed egg collection, the 8th-11th century settlers of Mývatnssveit felt the need to regularly provision themselves with marine products. This Viking age inland distribution of marine products (especially dried fish) is best documented in Mývatnssveit, but marine fish and sea mammal bones have also been recovered from early inland sites in eastern Iceland (Aðalból; McGovern 1982), inland Eyjafjord (Granastaðir, Einarsson 1994) and in western Iceland (Reykholt, Háls, McGovern 2004). The inland transfer of marine fish and other marine resources was definitely an established pattern in most parts of 10th century Iceland. However the acquisition of coastal resources was organized (chiefly staple goods exchange, paired inter-household transfers, labor service) it appears that even in the earliest days of settlement neither the single farmstead nor even the local district (*hreppur*) was in fact the basic unit of economic survival. We need to consider the role and importance of trade and exchange networks potentially connecting whole quarters of Iceland, and to take seriously the entrepreneurial role of chieftains who were evidently not simply managers of their own prosperous farms. New evidence of early specialized fishing settlements in northwest Iceland further suggest the existence of an extensive distribution network that predates the historical international fisheries of the later Middle Ages (Amundsen, Perdikaris et al 2005, Edvardsson 2004, in press, Krivogorskaya et al. in press). In light of these findings, the location of Hofstaðir at the juncture of the lake basin and the route along the Laxá valley to the sea may in itself be significant. Did an aspiring 10th century chieftain lacking high quality pasture land attempt to control the flow of marine resources inland as well as playing the religion card?

Sustainable and Unsustainable Resource Use on the Millennial Scale

The full results of the sustained support provided to the Landscapes of Settlement pattern are still appearing, but we can offer a number of important corrections to the previously accepted narrative of early settlement and human environmental impact.

- Settlement patterns at Landnám were far more complex than previously realized. Inland settlement (perhaps at what was then the upper boundary between woodland and highland pastures) was early – possibly pre-dating the occupation of the valley systems of the lower elevations.

- Political competition in the first two centuries of settlement was complex, and appears to have involved a range of strategies including the control of pasture resources, the manipulation of regional staple goods exchange, iron and charcoal production, and investment in pre-christian ritual and feasting. Following the adoption of Christianity, the clearance of the valley forests for settlement, and the depletion of at least some of the woodlands of the upper elevations, the economic and ritual landscape changed, affecting the political ecology of power and probably permanently relegating upland communities like Mývatnssveit to political and economic marginality. The collapse of the attempted "faith based" chieftainship at Hofstaðir probably reflected factors beyond the devaluation of an investment in a temple farm by change in cult, including changing patterns of trade and new routes to the sea that bypassed Hofstaðir.

- Early human impact in Mývatnssveit involved local, but not universal deforestation, and clearance may have been more gradual than in southern Iceland. Iron and charcoal production may have provided both additional pressure upon forest resources and an incentive to conserve woodland. The reduction in pigs and goats notable in the zooarchaeological record may well reflect efforts to slow forest destruction rather than a simple response to deforestation, as the faunal shift occurs at least a century before pollen evidence for effective deforestation. The most severe erosion is not associated with the initial settlement, but with later Middle Ages and early modern periods.

- Human impact on pasture communities and soils initially was very local. While the massive erosion catastrophe that began after 1717 has tended to create a homogenized, deflated gravel-field landscape in the worst impacted areas around the lake basin, site focused intensive soil science investigations backed by impact modeling reveal considerable differences between early management strategies and resulting human impacts in the different farm catchments. It is possible to reconstruct household – level land management practices while integrating these findings with regional-scale indicators.

- While information management maladies associated with colonization of deceptively familiar North Atlantic ecosystems certainly provided unwelcome surprises to early Icelandic settlers, the main cognitive challenges seem to have been associated with changes in climatic stability and predictability after the first century of Landnám. Patterns of landuse, traditional herding knowledge, and the critical timing for the end of upland grazing would all be impacted by changes in what had become a well-understood set of environmental parameters. "Tragedy of the commons" is an unlikely explanation for the eventual failure of herding systems to prevent large scale erosion. Inability to cope with radical increases in environmental variability is far more likely to be the ultimate cause of eventual catastrophic soil loss. This finding has major implications for modern attempts to sustainably manage agricultural systems in the face of rapid and increasingly unpredictable climate change. Successful local level management systems which have achieved broadly sustainable patterns of resource consumption for centuries may well be overwhelmed by the simultaneous rapid increases in rate of change coupled with simultaneous decrease in inter-seasonal predictability.

- Not everything went wrong. The Mývatn record indicates significant human response to changing environment, much probably aimed at resource management as well as chiefly aggrandizement. The eventual failure to conserve soils and pasturelands over much of the region can be balanced against the impressive record of successful sustainable management of the migratory bird population of Mývatn. Some remedies were probably applied too little and too late, others may have been frustrated by rapid and unpredictable climate change or by simple inability to predict volcanic eruptions or external political changes. However, the pastures are still green around Hofstaðir, and the waterfowl still come in

> their thousands each spring. These features of the landscape of Mývatnssveit are as much a result of a thousand years of human environmental management as the eroded hills beyond the lake.

Science Management Lessons Learned

The experience of committing a decade of international, interdisciplinary effort to Mývatnssveit has provided some humbling lessons. Some of the most difficult issues limiting effective interdisciplinary cooperation (especially between social and natural scientists) are the manifold problems of scale-matching. Had the investigations been limited to a typical archaeological project of two or three seasons of intensive excavation on a single site combined with a catchment survey we would have totally misunderstood the larger regional pattern, and would have lacked the comparison of nearby sites that provide some basis for sorting out variability due to time, place, environmental change, and chance. If a broad-brush regional scale approach had been applied, based on site survey backed by a few soil profiles or pollen cores, we would have also come to a largely false appreciation of the actual dynamics of human-environmental interactions in the study area. Combining operational scales in data collection by joining intensive excavation and on-site paleoenvironmental sampling with extensive field walking and wide spread soil cores and geological profiles provided the data needed to realistically ground truth our grazing impact models and to fuel GIS projects without excessive amounts of speculative interpolation. The other major problem facing all cross-disciplinary teams is moving beyond multi-disciplinary "parallel play" (each discipline makes a separate contribution) to genuinely interdisciplinary "cooperative play" (disciplines actually integrate data and approaches in a coordinated attack on a common problem, see Broadbent 1996). The marvelous isochrones provided by the well-studied Icelandic tephra have been invaluable, but the single greatest asset to effective integration has been prolonged field work involving sustained focus upon a common set of problems within a common research area.

Persistence may matter more than project size- small well integrated teams collecting data for multiple summers (and arguing over analytical patterns each winter) in this case accomplished more effective integration than a single, huge multi-investigator project limited to a few seasons (the first of which tends to be inevitably spent in logistic and coordination struggles). But however achieved, the size of the different disciplinary data sets does matter greatly; multiple site collections, large ecofact counts, hundreds of soil profiles all provide the solid basis for cross-disciplinary discussion and integration that is nearly impossible to achieve from a pastiche of small scale, short term investigations. If we are to successfully contribute to the archaeology of global change we need to develop structures of funding and research support that will promote similar sustained long term cooperative investigations with a clear landscape focus.

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Figures and tables

Figures
1, Location map
2 cow skull
3. Pollen profile-
4. C14 chronology- needs labels
5, Andy climate
6. Major taxa comp
7. caprine/cattle
8 fish element picture- convert to bw

table
1. radiocarbon and delta c13 table

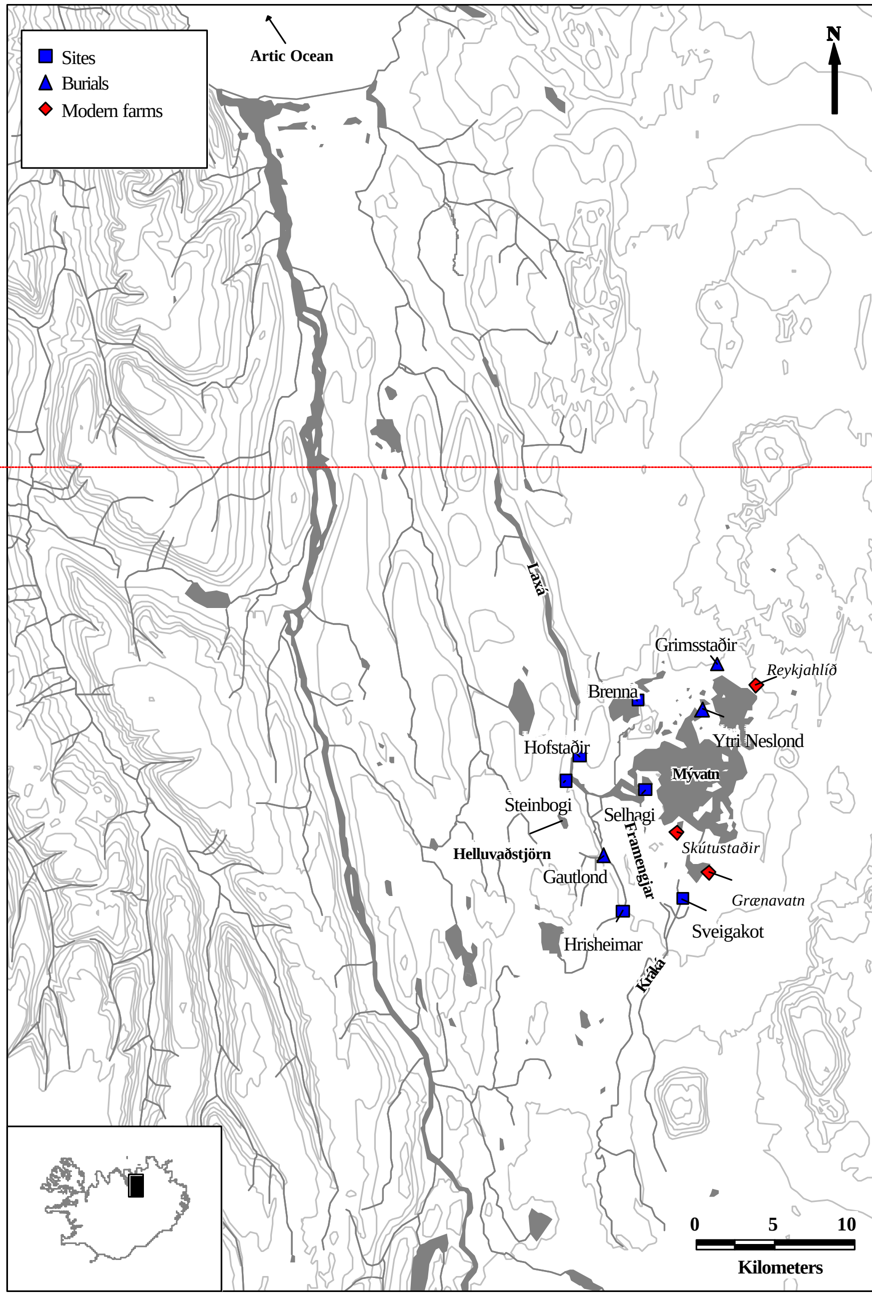

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Figure 1 – General Location map, ,

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Figure 2 – Bull's skull from wall demolition at Hofstaðir. Depressed fracture between the eyes is typical of these specimens, as is differentially heavy weathering on the outer surface and the intact horn cores. Fractured during 11th c demolition of the great hall, this partial skull and set of horns seems to have been displayed for some time on the outside of the building.

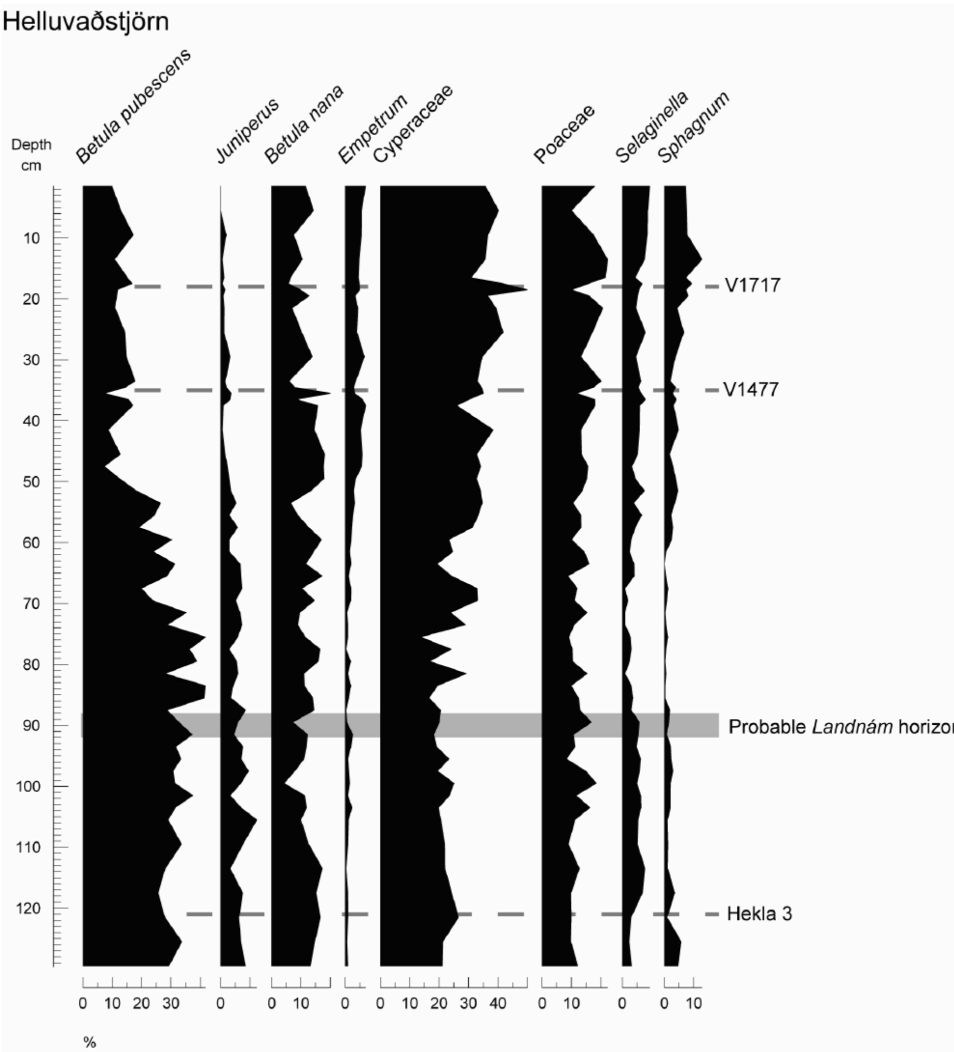

figure 3 Summary pollen diagram from Helluvaðstjörn. Tephra isochrones have been identified by microprobe analysis at Hekla-3, V1477, and V1717. The probable Landnám horizon is marked by the onset of soil erosion within the catchment and by a step change in the productivity of the lake, both of which are presumed to be anthropogenic.

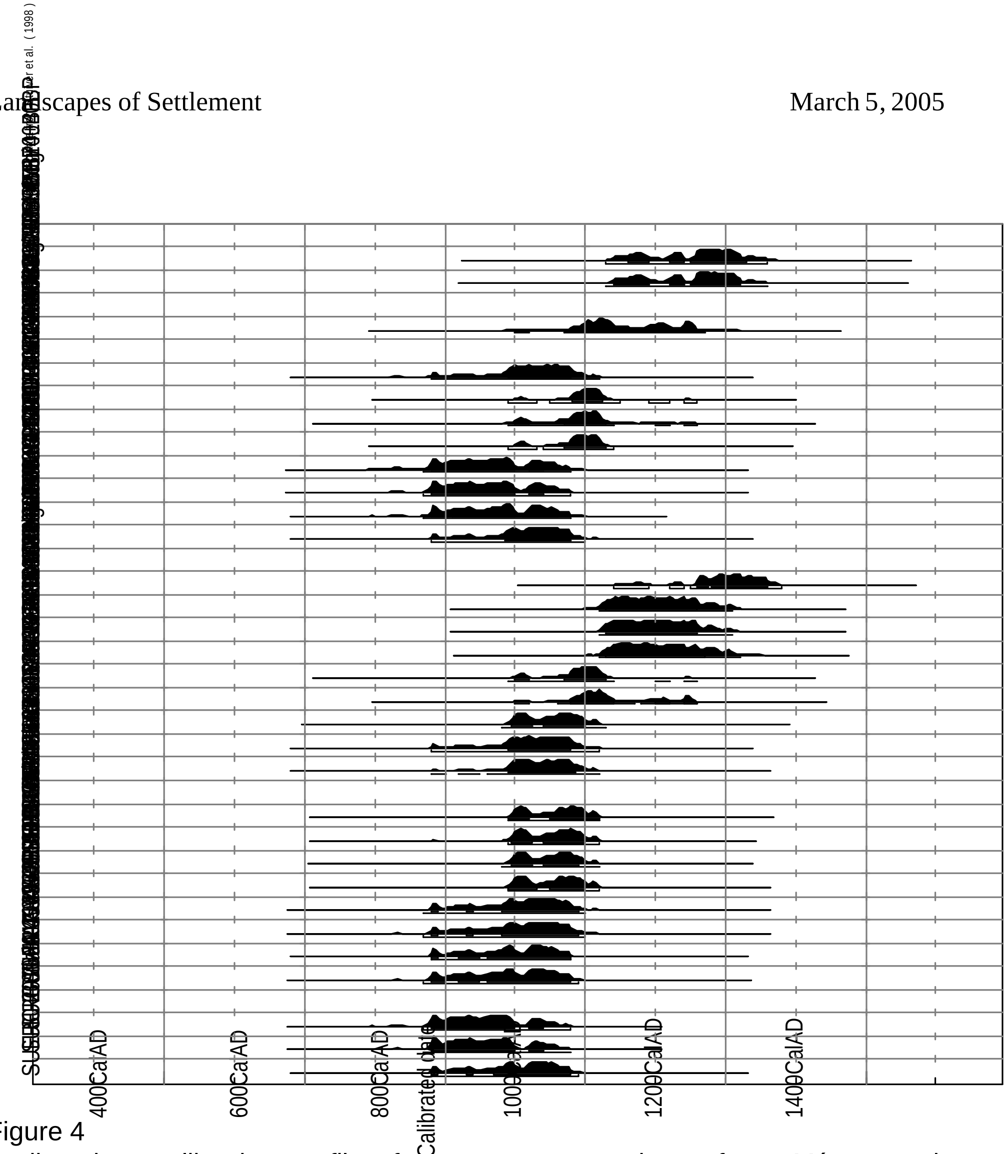

Figure 4
Radiocarbon calibration profiles for dates from Mývatnssveit with terrestrial isotopic carbon ratios, in stratigraphic order . For laboratory data see table 1.

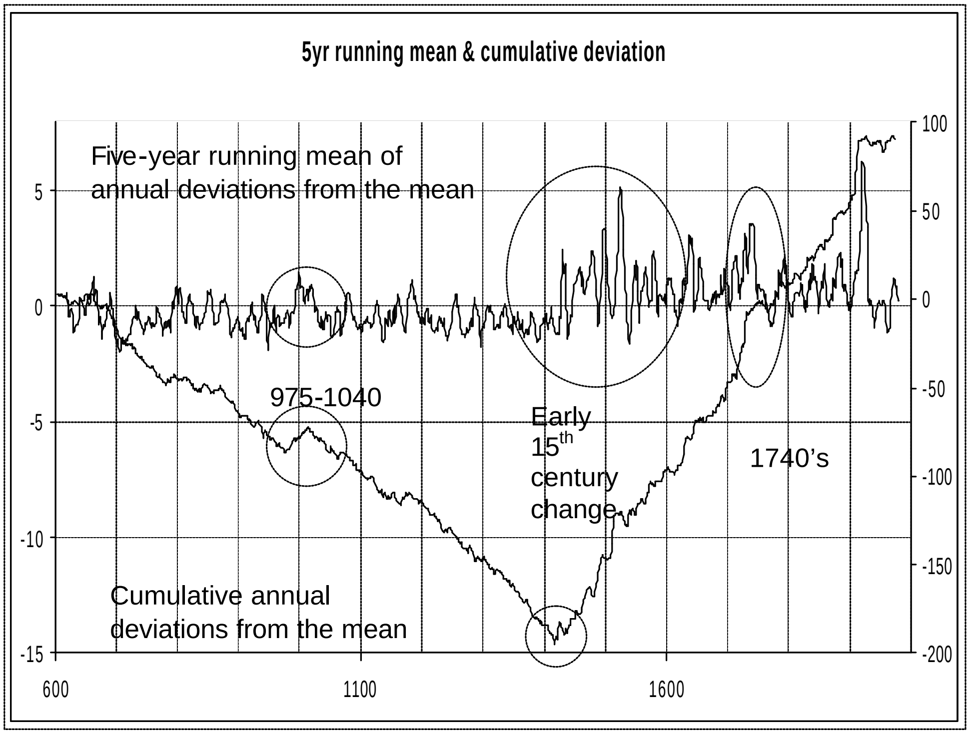

Figure 5, GISP-2 proxy storminess data. Deviations from mean PPB Na+ (left hand scale), cumulative deviations from the mean PPB Na+ (right hand scale). The cumulative annual deviations from the overall mean show a key change in 1425, a turning point when established patterns of change became a misleading guide to the future. Similar, but less sustained changes occurred earlier at 975 and 1040; later, extreme events (for example the changes of the 1740's) seem to have become more characteristic,

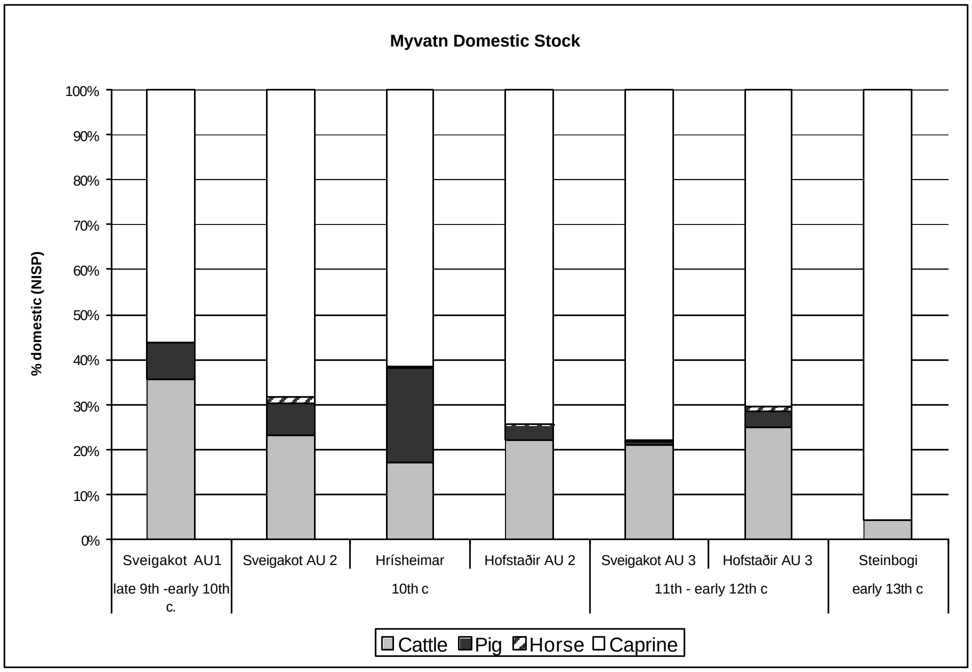

Figure 6 Changing relative proportions of domestic mammals from 9th-early 13th centuries for larger Mývatnssveit archaeofauna. Note the decline of pigs: in the same time period “caprines” (both sheep and goats together) become nearly all sheep as goats also decline with time.

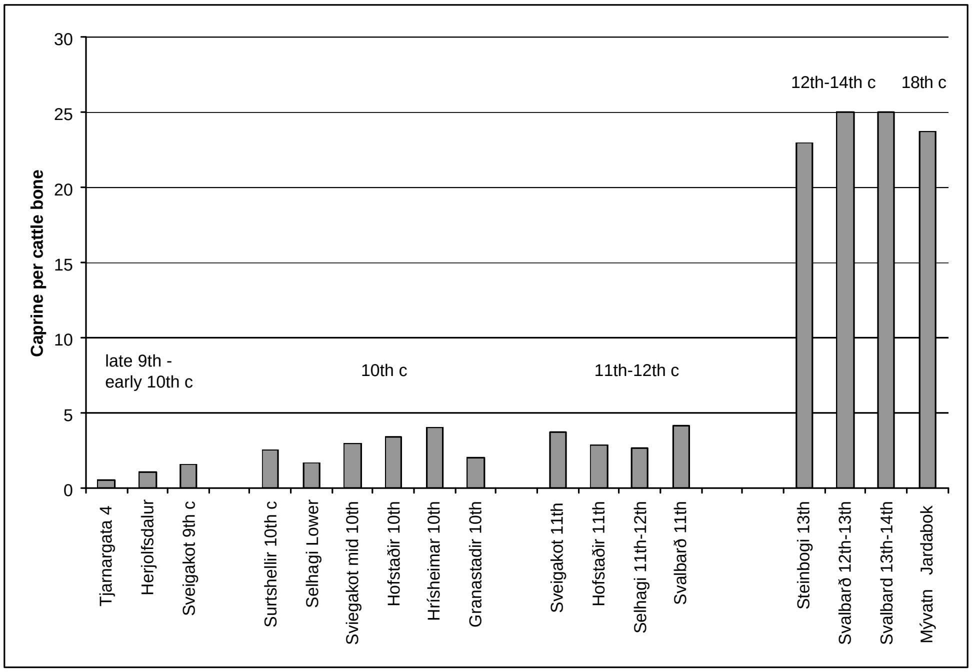

Figure 7 Changing ratios of caprine (sheep and goat) and cattle bones from larger archaeofauna spanning the 9^{th}-14^{th} century in Iceland. The earliest archaeofauna tend to have the highest ratio of cattle to caprine bones, but the pattern differs between regions. Higher status sites tend to have more cattle. The conversion to a largely sheep-based farming strategy appears to occur in the late 12^{th}-early 13^{th} century.

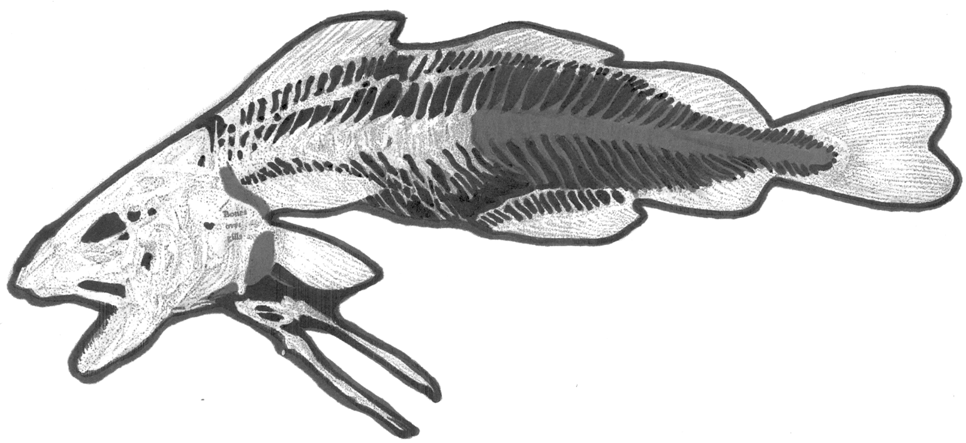

Figure 8 Cod skeleton with parts found on the inland Mývatnssveit sites indicated in darker tone. Note that the head and upper vertebral elements are missing, apparently left at a coastal processing site. This pattern is seen uniformly in all Mývatn archaeofauna.

Table 1 – ^{14}C Ages and delta^{13}C values for animal bones from domestic middens and pre-Christian burials from Mývatnssveit

Site and Lab Reference #	Context & Species	Context description	Delta ^{13}C (‰)	Delta ^{15}N (‰)	C/N Ratio	Radiocarbon age (years BP)	95.4% confidence range (AD)
DOMESTIC MIDDEN SAMPLES							
Hofstaðir							
Beta 149404	HST G 008 cow	pit house floor	-21.5			1130 ± 40	780-1000
SUERC-3429	HST 7a cow	lower pit house fill	-21. 0			1160 ± 35	770-980
SUERC-3430	HST 7a pig	lower pit house fill	-21.0			1170 ± 40	770-980
Beta 124004	HST G 6n cow	lower pit house fill	-21.4			1170 ± 40	770-980
SUERC-3431	HST 6d cow	upper pit house fill	-20.3			1045 ± 35	890-1040
SUERC-3432	HST 6d pig	upper pit house fill	-21.5			1040 ± 40	890-1160
SUERC-3433	HST 6g cow	upper pit house fill	-20.9			1030 ± 35	890-1160
Beta 149403	HST G 004 cow	upper pit house fill	-21.7			1120 ± 40	780-1020
Beta 149405	HST E 1144 cow	outside hall	-21.6			1060 ± 50	880-1160
Sveigakot							
Beta 134146	SVK M 011 cow	Lower midden M	-21.0			1110 ± 40	780-1020
Beta 134144	SVK M 002 cow	Upper midden M	-21.0			1120 ± 40	780-1020
Beta 134145	SVK M 012 sheep	Upper midden M	-19.3			1090 ± 40	880-1030
Beta 146583	SVK T 055 cow	upper fill of pit house T	-22.7			1040 ± 40	890-1160
Beta 146584	SVK T 055 cow	upper fill of pit house T	-21.5			1010 ± 40	900-1160
Hrísheimar							
AA-49627	HRH 003 cow H	Midden fill of pit house	-20.7			1150 ± 35	780-980
AA-49628	HRH 003 cow H	Midden fill of pit house	-21.0			1135 ± 45	770-1000
AA-49629	HRH 003 cow H	Midden fill of pit house	-20.2			1135 ± 45	770-1000
SUERC-3439	HRH 003 cow H	Midden fill of pit house	-20.9			1085 ± 35	890-1020
SUERC-3440	HRH 003 pig H	Midden fill of pit house	-21.3			1150 ± 40	770-990
SUERC-3441	HRH 003 cow H	Midden fill of pit house	-22.0			1095 ± 35	880-1020
SUERC-3445	HRH 060 cow N	Lower midden N	-20.9			1090 ± 35	890-1020
SUERC-3442	HRH 002 pig H	Deflated upper deposit	-20.1			1120 ± 35	810-1000
SUERC-3446	HRH 002 cow N	Deflated upper deposit	-21.4			1080 ± 35	890-1020
Selhagi							
AA-49630	SLH1 01 004 cow	Upper midden	-21.1			960 ± 45 BP	990-1190
AA-49631	SHL2 01 004 cow	Upper midden	-20.8			995 ± 45 BP	970-1170
Steinbogi							
AA-52498	SBO 002 Cow	Main surviving midden deposit	-21.4			875 ± 40 BP	1030-1260
AA-52499	SBO 002 Cow	Main surviving midden deposit	-20.5			870 ± 40 BP	1150-1230
PRE-CHRISTIAN BURIALS							
Gautlönd, Skútustaðahr							
SUERC-2026	Human GLÞ-A-1		-19.5	8.4	3.0	1200 ± 35	
SUERC-2663	Human GLÞ-A-1		-19.7	7.7	3.0	1175 ± 35	
SUERC-2664	Dog		-20.5	8.3	2.9	1175 ± 35	

Grímsstaðir, Skútustaðahr						
SUERC-2018	Human GRS-A-1	-19.3	10.0	3.1	1225 ± 35	
SUERC-2019	Horse 1967-213	-21.0	1.7	3.1	1145 ± 35	* 880-990
SUERC-2662	Horse 1967-213	-20.7	1.2	3.0	1105 ± 35	
Ytri-Neslönd, Skútustaðahr						
SUERC-2016	Human YNM-A-1	-18.9	9.7	3.1	1395 ± 35	
SUERC-2660	Human YNM-A-1	-19.3	8.3	3.1	1405 ± 35	
SUERC-2017	Horse 1960-46	-21.8	2.7	3.2	1175 ± 35	** 770-900
SUERC-2661	Horse 1960-46	-21.7	2.0	3.1	1200 ± 35	
Þverá, Reykdælahr						
SUERC-2039	Human 2000-3-1	-19.7	8.7	3.1	1235 ± 35	

* calibrated range (95.4% confidence) derived from the weighted mean age of SUERC-2019 and SUERC-2662 (1125 ± 25 yr BP)
** calibrated range (91.4% confidence) derived from the weighted mean age of SUERC-2017 and SUERC-2661 (1188 ± 25 yr BP)

All calibrations were undertaken using the OxCal Program which uses the INTCAL98 data (Stuiver M. et al 1998 INTCAL98 Radiocarbon Age Calibration, *Radiocarbon* 40(3):1041-1083.)
All AMS ^{14}C were made on extracted bone collagen