Coastal connections, local fishing, and sustainable egg harvesting: patterns of Viking Age inland wild resource use in Mývatn district, Northern Iceland

Thomas H. McGovern, Sophia Perdikaris, Árni Einarsson and Jane Sidell

The 'Landscapes of Settlement Project' has carried out archaeological and paleoenvironmental research in the Lake Mývatn region of N. Iceland since 1996. Animal bone collections dating from the late 9th century to the early 13th century AD have been recovered from five sites in different ecological zones around the lake, and three of these sites provide multiple phases datable through radiocarbon, artefacts, and volcanic tephra. Modern systematic biological and geological investigations in the Mývatn district date to the 19th century and a detailed picture of the recent ecology can be combined with both archaeological and historical evidence for long term resource exploitation by humans in this inland region. Analysis of bird bones and bird eggshell suggests that the locally managed sustainable harvest of migratory waterfowl eggs carried out over the last 150 years extends back to the 9th century. These inland archaeofauna also include significant numbers of marine fish and sea birds, marine mollusca, and a few seal and porpoise bones. Marine fish remains recovered indicate specialised transport of partial skeletons missing most cranial and some thoracic vertebrae, suggesting that a cured fish product was being regularly brought to inland farms during the early years of the settlement. Inter-regional exchange and a pre-Hanseatic artisanal fish trade prior to AD 1000 suggests the importance of preserved marine fish in early Scandinavian economies, and may shed light on the source of the 11th century 'fish event horizon' recently documented in southern Britain.

Keywords: zooarchaeology, cod, trout, char, ducks, ptarmigan, seabirds, Mývatn

Introduction

This paper investigates wild resource use by the early Scandinavian settlers of the highland interior Lake Mývatn basin in northern Iceland during the 9th–13th centuries. It combines the results of long-term archaeological and paleoecological investigations by the *Landscapes of Settlement* project (directed by Orri Vésteinsson and Adolf Friðriksson of the Archaeological Institute, Iceland), early 18th-century landuse records, and sustained modern biological investigations carried out by the Mývatn Research Station and the University of Iceland. Fuller discussion of the project's new evidence for domestic mammal herding patterns, settlement evolution, human environmental impact, and pre-Christian ritual activity is presented elsewhere (Dugmore *et al.* 2005; Edvardsson 2004a; 2004b; Friðriksson 1993; Friðriksson and Vésteinsson 1993;1995; 1996; 1997a; 1997b; 1998a; 1998b; 1998c; 1998d; Friðriksson and McGovern 2005; Friðriksson *et al.* 2004; Lawson *et al.* 2005; Lucas 1998; 1999; 2000; 2001; 2002; 2004; McGovern 1999; Ogilvie and McGovern 2000; Perdikaris *et al.* 2001; Perdikaris and McGovern 2006; Simpson *et al.* 1999; Simpson *et al.* 2001; Simpson *et al.* 2003; Simpson *et al.* 2004; Vésteinsson 1998; 2000; 2001; 2002; 2003; 2004a; 2004b; 2005;

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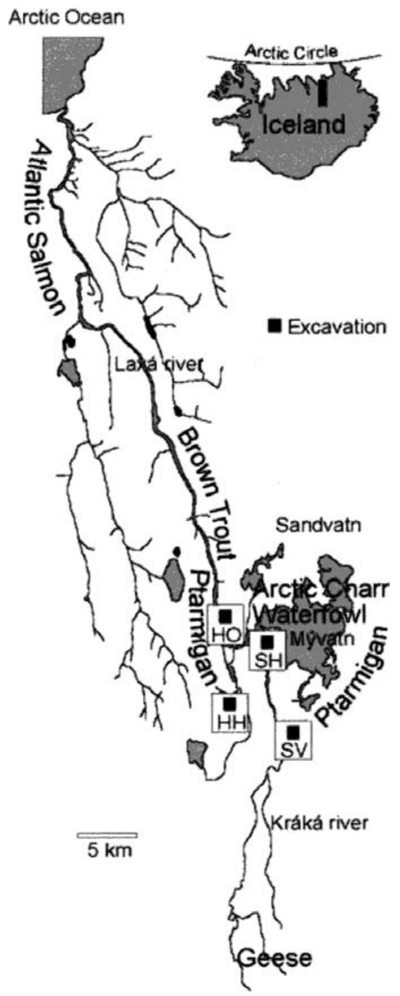
Vésteinsson *et al.* 2002; Vésteinsson and Simpson 2004).

Archaeological sites and environmental context

The Mývatn region (Mývatnssveit) straddles the Mid-Atlantic rift, and has been volcanically active for thousands of years. The broad shallow lake has a complex ecology that supports the arctic charr (*Salvelinus alpinus* L.) and brown trout (*Salmo trutta* L.) as well as the vast population of chironomid and simuliid flies that provide its name (‘*midge lake*’). The lake provides significant climatic amelioration despite its high altitude (250–300 m above sea level) and the district supports rich hay fields and wet meadows, especially along the south side of the lake. 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 lake is fed by underground channels, and the major drainage is the Laxá River flowing northwards to Skjálfandi Bay on the Arctic Ocean approximately 60 km away. The Laxá (‘salmon river’) is a famous trout stream and in its lower reaches also receives migratory Atlantic salmon (*Salmo salar* L.), 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 lakes surround Mývatn and also provide 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. Ptarmigan (grouse, *Lagopus mutus* L.) are present in upland heaths surrounding the lake, as are arctic fox (*Alopex lagopus* L.). The whole region has undergone profound environmental change since human settlement in the late 9th century, when the interior deserts were probably at least partially wooded, the wet meadows south of the lake were more extensive, and the low lying valleys supported dense stands of birch and willow. New pollen evidence from Helluvaðstjörn near Mývatn suggests a more gradual deforestation after first settlement than is evident from pollen cores in southern Iceland, with some woodland persisting into the early Middle Ages (Hallsdóttir 1987; Lawson *et al.* 2005). It appears that widespread charcoal production and substantial local iron smelting were features of the economy of the late 9th and 10th centuries AD, as numerous charcoal pits and iron smelting activity have been documented by the Landscapes of Settlement project (Edvardsson 2005a). The value of local dwarf trees for charcoal production as well as for construction possibly contributed both to early attempts at woodland conservation and to eventual deforestation (Edvardsson 2004b).



1 Location map for the study area, with resource concentrations indicated

The archaeological sites whose animal bone collections are reported here are located in three contrasting environmental zones within Mývatnssveit (Fig. 1). ***Hofstaðir*** (HST) is located in the upper Laxá drainage, with overland connections northward down the Laxá valley to its junction with Skjálfandi bay (Arctic Ocean) near the modern town of Húsavík. Hofstaðir apparently became a major chieftain’s farm in the 10th century, and has long been archaeologically known for its huge long hall and associated complex of buildings (Bruun and Jónsson 1909; 1911; Olsen 1965). The Laxá valley around Hofstaðir is today largely deforested, but maintains a rich cover of grass-sedge-herb communities which grow particularly lushly around the river banks themselves. Hofstaðir is still occupied and was an

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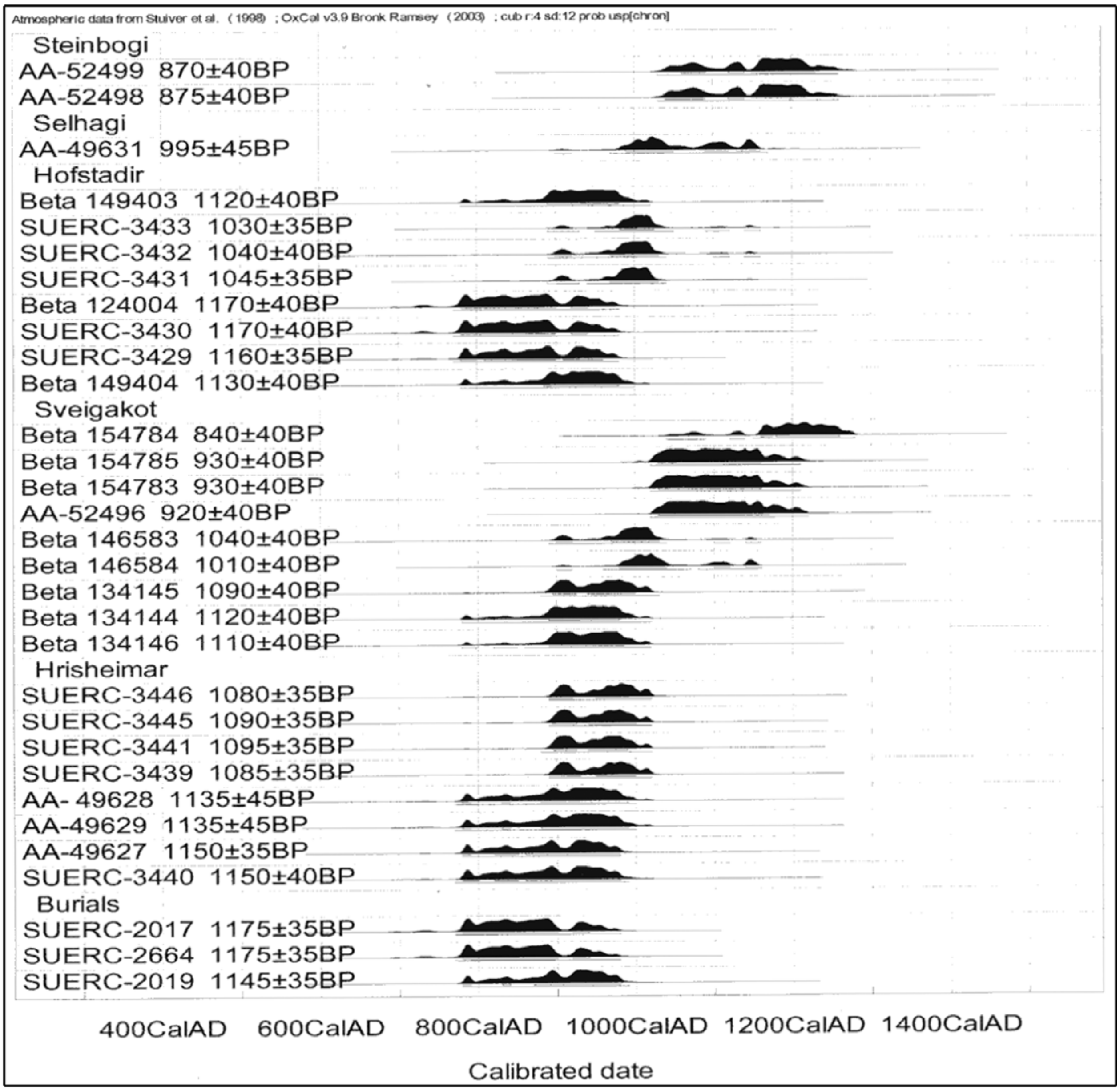
upper-/middle-ranking (but not elite) farm in the later medieval period. Hofstaðir has been extensively excavated by the Archaeological Institute Iceland (Fornleifastofnun Íslands) between 1992–2001, and major stratified bone collections from the site's middens spanning the 10th-early 12th centuries are reported here. ***Steinbogi*** (SBO) is a small abandoned site on a bluff overlooking the Laxá just to the south of Hofstaðir. This small site has been damaged by past turf cutting and is now partially removed by highway construction, but rescue work in 2002 recovered a quantifiable stratified archaeofauna from a midden dating to the early 13th century (Vésteinsson 2004a). ***Selhagi*** (SLH) is a small abandoned ruin located among the complex set of channels and small islands at the juncture of the Kraká with the Laxá in a well vegetated ancient lava field. Selhagi is in the immediate lakeshore zone, with direct access to rich freshwater fishing and migratory waterfowl nesting areas. In 2001 a small-scale midden excavation produced a stratified archaeofauna that rests upon the Landnám tephra sequence (dated to AD 871+/−2 on the basis of the GISP2 and GRIP ice cores, Gronvold *et al.* 1995) and extends into the 12th century (McGovern *et al.* 2001; Vésteinsson 2004a). ***Sveigakot*** (SVK) and ***Hrísheimur*** (HRH) are both long-abandoned farms in the Kraká river drainage to the south of the lake; lying around 300 m above sea level and today existing only as heavily eroded ruins. Sveigakot is on the east side of the Kraká, and is now located on an eroded gravel plain at the edge of the inland desert. Excavations at Sveigakot since 1999 have produced both substantial animal bone collections and a multi-phased occupation involving at least one period of abandonment and re-occupation in the 10th century. The later household at Sveigakot occupied a much smaller dwelling and was probably substantially less prosperous than were the original settlers. Sveigakot's second occupation also eventually failed, and the site was permanently abandoned in the early 12th century (Vésteinsson 2002; 2003; 2004b; 2005). Hrísheimur occupies what is today a heavily eroded ridge overlooking a small bog on the west side of the Kraká. The farm was involved in iron production as well as agriculture, maintaining a series of substantial smelters along the ridgeline processing bog iron probably extracted nearby. Hrísheimar is also associated with a pre-Christian burial (robbed in antiquity) which produced a single domestic dog (*Canis familiaris* L.) bone which radiocarbon dated to the 9th century AD (Friðriksson and McGovern 2005). The site is today badly eroded, but appears to have been a substantial medium-to-high status site established soon after first settlement but abandoned prior to the fall of the Hekla AD 1104 tephra. Hrísheimar's extensive midden deposits are still under excavation, and while we report a substantial sample in this paper which we feel reasonably represents overall patterning, it should be noted that this site's archaeofauna will expand significantly as excavation continues into 2007 (Edvardsson 2004a; 2005a).

The five sites in the current sample thus occupy interconnected but contrasting ecosystems.

1. Upper Laxá river valley (Hofstaðir, Steinbogi)
2. Lakeshore margins (Selhagi)
3. Kráká river valley (Sveigakot, Hrísheimur)

Dating

The Landscapes of Settlement project has been fortunate in being able to combine a suite of internally consistent AMS radiocarbon dates with the results of intensive ongoing research into the local volcanic tephra sequences by Magnus Sigurgeirsson (in Vésteinsson 2004b; 2005), Gudrun Larsen, Andy Dugmore and Anthony Newton (Dugmore *et al.* 2000; Dugmore *et al.* 2004). There are multiple medieval tephra horizons in the Mývatn sequences, the most important for our purposes being the AD 871+/−2 Landnám tephra (dated by its presence in the Greenland ice cores: Gronvold *et al.* 1995), a *c.* AD 900-50 Veiðivötn ash, and the Hekla AD 1104 and 1158 ashes. The combination of the Landnám tephra and the early 10th-century Veiðivötn tephra have allowed phasing of the Sveigakot and Hrísheimar sheet middens and correlation with deposits at Hofstaðir and Selhagi. Both radiocarbon and tephra provide complimentary frameworks for dating (allowing partitioning of the 10th-century radiocarbon calibration plateau), and the recovered artefact assemblages (which include single-sided composite combs, glass and amber beads, steatite artefacts, and a range of bone pins) are all consistent with a Viking Age date. Fig. 2 presents the AMS radiocarbon dates (kindly provided by Gordon Cook of SUERC) currently available for the midden deposits at the five sites, making use only of samples drawn from domestic mammal bone collagen showing fully terrestrial delta 13C ratios). The midden deposits at these five sites can be grouped into phases (analytic units, AU) making use of both radiocarbon dates and tephra. The initial settlement of Mývatnssveit in late 9th-early 10th century is demonstrated stratigraphically by culture layers in



2 AMS Radiocarbon dates (all on bone collagen showing entirely terrestrial delta 13C) for the midden deposits generating the archaeofauna presented in this paper. Arranged by site in stratigraphic order, with laboratory reference and radiocarbon assay value and standard deviation provided

direct contact with the Landnám tephra (at the sites of Selhagi, Brenna, Hrísheimar, and Sveigakot), and by 9th-early 10th-century radiocarbon dates on horse (*Equus caballus* L.) bones from pre-Christian burials (at Grimsstaðir and Ytri-Neslond). At Sveigakot a quantifiable archaeofauna has been recovered from between the Landnám sequence and the early-mid-10th-century Veiðivötn tephra (Sveigakot AU 1). While substantial midden deposits similarly stratified between Landnám and the 10th-century Veiðivötn tephra at Hrísheimar were localised by field work in 2005, these deposits are still under excavation and the Sveigakot AU 1 archaeofauna remains the earliest substantial collection reported here. By the mid-10th century (above the Veiðivötn tephra) it is possible to compare four archaeofauna (Sveigakot AU 2, Hrísheimar AU 2, Hofstaðir AU 3, Selhagi AU 1). Radiocarbon dates and artefacts place three archaeofauna in the 11th-early 12th centuries (Sveigakot AU 3, Hofstaðir AU 4, Selhagi AU 2), while a single collection dates to the early 13th century (Steinbogi).

Excavation, recovery, and analysis

The archaeofauna reported here were all collected from stratigraphically excavated contexts, 100% dry

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sieved (4 mm mesh) backed by an approximate 5% sub-sample saved for flotation (Ankara type apparatus). Fragment size analyses indicate extensive recovery of bone fragments with maximum dimension of 1–2 cm by the dry sieving program, and test sieving of spoil through 1 mm mesh did not reveal any substantial loss of bone. All samples appear to have experienced generally similar taphonomic histories in terms of fragmentation, carnivore gnawing, and burning, and show similar proportions of very dense and less dense skeletal elements. They derive from deposits with a broadly similar level of soil acidity (pH range 6·25–6·75). The overall condition of the bone material can be rated as very good to excellent, and fishbone and molluscan shell were generally well preserved as well as mammal and bird bone and bird eggshell. The collections reported here also come from the same sort of archaeological deposits: accretional midden composed of stratified domestic refuse either dumped directly on the ground (Sveigakot, Selhagi, Hofstaðir) or into an abandoned sunken-feature structure (Sveigakot, Hrísheimur, Hofstaðir). All these midden contexts contained similar proportions of wood charcoal, ash, fire cracked stones, industrial waste, and lost or discarded artefacts. Mammal bone butchery and skeletal element distribution study indicates that these deposits received both primary butchery waste and the residue of meals and fireplace cleaning. Seasonal indicators (eggshells, newborn mammals) from all four sites suggest that spring/summer was a major season for midden accumulation at all farms. These midden deposits seem to have accumulated refuse from multiple household activities and represent a generalised deposit of farm garbage rather than a specialised deposit or processing area. Bone material collected from structural contexts associated with floor deposits are generally subject to a different range of behavioral and taphonomic processes and are not included in the present analysis. Within the limits of any archaeological investigation, we feel that the midden archaeofauna reported here are thus broadly inter-comparable. The main present limitation on inter-site comparability remains the smaller sample sizes currently available from Selhagi which limits comparisons with the larger archaeofauna.

Wild and domestic resource use in Iceland: an overview

The settlement (Landnám) of Iceland in the late 9th century brought NW European species and a late Iron Age economy to an isolated mid-Atlantic island that had probably never before seen significant human presence (Buckland 2000; Vésteinsson 2000). Domestic mammal bones in early North Atlantic archaeofauna indicate the introduction of a farm management complex that included many cattle (*Bos taurus* dom. L.), some pigs (*Sus scrofa* dom. L.), and a mix of sheep (*Ovis aries* dom. L.), goat (*Capra hircus* dom. L.), and horses (McGovern *et al.* 2001). However, the same early collections also indicate the extent to which locally available wild resources were employed to underwrite the initially limited domestic animal component of the colonists' subsistence economy. Archaeofauna from early settlement sites in southern Iceland are dominated by sea birds, recalling the several (much later) saga references to 'unwary' wild animals at Landnám (Vésteinsson *et al.* 2002, McGovern *et al.* 2001). In the early Commonwealth period (11th–12th centuries) there is a general shift in species exploitation, with domestic mammals coming to dominate the collections. In later medieval to early modern times (14th–18th centuries), marine fish become the source of the most common bones in virtually all collections (Amorosi 1996; Amundsen *et al.* 2005; Edvardsson *et al.* 2004).

Zooarchaeological evidence for wild species use in Mývatnssveit

Table 1 presents the bone fragments identifiable to a useful taxonomic level (NISP) for the archaeofauna reported here and also presents the less identifiable bone fragments included in the total number of fragments (TNF) for each phase. The two phases from Selhagi (SLH) are only marginally quantifiable because of sample size, but are presented here for completeness. While domestic mammals probably made up the core of the economy at all sites throughout the settlement, fish and bird bones make up a varied, but often substantial proportion of the total collection for each phase.

Table 2 presents a breakdown of the identified mammal taxa from the Mývatnssveit archaeofauna (the small Selhagi archaeofauna is again included for reference only). The substantial amounts of cattle, pig, and goat bones in the 9th–12th-century archaeofauna again confirm the diversity of the Landnám farming strategy, but declining proportions of pigs and goats and rising percentages of sheep signal the major economic transition evident in the 13th–century Steinbogi archaeofauna (whose sheep-dominated collection shows signs of management for wool production, McGovern *et al.* 2001). By the 13th century, the complex settlement age farmyard had been effectively simplified to a sheep-based (and

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Table 1 Overview of Mývatnssveit archaeofauna, presenting identified fragment counts (NISP) and all fragments (TNF) by site and phase. Large terrestrial mammal bones are from horse/cow-sized animals, medium terrestrial mammal bones are from sheep/pig/large dog-sized animals, and small terrestrial mammal bones are from cat/fox/small dog-sized animals. (SVK = Sveigakot, HST = Hofstaðir, HRH = Hrísheimar, SBO = Steinbogi, SLH = Selhagi)

Site	SVK 1	SVK 2	HRH 2	HST 3	SLH 1	SVK 3	HST 4	SLH 2	SBO
Date in centuries	9th–10th	10th	10th	10th	10th	11th	Late 10th–11th	12th	Late 12th–13th
Domestic mammals	688	1619	1612	2410	137	5798	4181	136	1083
Seals	2			2			11		
Whale	1	1	1	2			5		1
Birds	24	634	345	65	23	529	261	2	59
Fish	433	3573	801	9681	178	4499	15548	394	151
Shellfish	1	13	23	267	2	1	449	3	8
total NISP	1149	5840	2782	12427	340	10827	20455	535	1302
Large terrestrial mammal	123	485	339	595	35	782	1231	29	27
Medium terrestrial mammal	456	1707	1611	2557	170	3615	4427	114	1381
Small terrestrial mammal		7		12		22	85		
Unidentifiable fragment	2574	5517	6987	10008	563	7897	25634	602	4165
total TNF	4302	13556	11719	25599	1108	23143	51832	1280	6875
Bird egg shell			xxx	xxx	xxx		xxx	xxx	xxx

cattle-supplemented) economy similar to that documented by the comprehensive 18th-century stock and landuse register *Jarðabók* (compiled for Mývatn in autumn 1712, JÁM 1990), where sheep to cattle ratios average 20:1. The Hofstaðir 10th–11th-century house interior collection also included a small number of cat (*Felis domesticus* L.) and mouse bones not tabulated in these midden archaeofauna (*Mus musculus* L. were identified on teeth, postcranial bones may include *Apodemus sylvaticus* L.).

The bones of the arctic fox are present in limited numbers in many Icelandic archaeofauna, reflecting the long interaction of human hunters with this single indigenous Icelandic terrestrial mammal. The substantial number of fox bones recovered from the midden deposits at Sveigakot (AU 2 and AU 3) are less typical, and do not represent articulations (these are bagged as units in the field and counted as a single NISP). Minimum number of individuals (MNI) for Sveigakot AU 2 is 10 (based on cranial fragments) and for Sveigakot AU 3 is 12 (based on metapodials). Fine slice marks are present on 40% of the fox bones, concentrating on crania and metapodials. While some whole fox carcasses were deposited at Sveigakot, study of articulated deposits indicate that heads and paws were differentially concentrated, suggesting skinning and final pelt processing took place fairly regularly during both major periods of occupation at Sveigakot. This may reflect a persistent specialisation of this farm, or the easy trapping possibilities presented by the nearby lava field to the east.

More surprising is the presence of small numbers of seal and cetacean bone on these inland sites. The

Table 2 NISP count of mammals from the Mývatnssveit archaeofauna. 'Caprine' refers to bones that could come from either sheep or goat. (SVK = Sveigakot, HST = Hofstaðir, HRH = Hrísheimar, SBO = Steinbogi, SLH = Selhagi)

	Site	SVK 1	SVK 2	HRH 2	HST 3	SLH 1	SVK 3	HST 4	SLH 2	SBO
	Date in centuries	9th-10th	10th	10th	10th	10th	11th	Late 10th-11th	12th	Late 12th-13th
Species	Species common name									
Bos taurus L.	Cattle	246	374	274	525	52	1220	1027	37	47
Sus scrofa L.	Pig	55	118	341	84		46	188		
Equus caballus L.	Horse	1	21	4	8		8	36		
Capra hircus L.	Goat	15	15	22	33		22	52	1	1
Ovis aries L.	Sheep	42	100	140	263	11	286	251	13	163
Caprine	Sheep or Goat	329	991	831	1497	74	4216	2627	85	872
	Total domestic	*688*	*1619*	*1612*	*2410*	*137*	*5798*	*4181*	*136*	*1083*
Alopex lagopus L.	Arctic fox	2	42	1	1		51	5		
Phocid sp.	Seal species indet.	2			2			11		
Small Cetacean sp.	Porpoise/small whale	1		1	1					
Cetacea sp.	Whale species indet.		1		2			5		1

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few seal bones probably came from harbor (common) seals (*Phoca vitulina* L.) from their size, but they cannot be securely identified to species. Four articulated porpoise tail vertebrae (species indeterminate, but in the size range of the common porpoise) were recovered in 2001 from the lowest layers of the Sveigakot midden (AU 1), one bearing a butchery mark from a heavy chopping blow. A few very cut up fragments of larger whale bone recovered from the other sites probably reflect use as raw material for tool fabrication, and are less likely to represent imported meat than the segment of porpoise tail discarded at Sveigakot. While it appears that sea mammals contributed only sporadically to the diet and economy of the early Mývatn settlers, the presence of any sea mammal bone this far inland is remarkable.

Table 3 presents the breakdown of bird bones from the Mývatn archaeofauna (again the Selhagi collections are probably best seen as incomplete species lists). While a diverse range of species are represented, virtually all the bird archaeofauna are dominated by bones of ptarmigan (grouse, *Lagopus mutus* L.), commonly found in the upland heaths and easily taken in snares (especially in winter). Nearly all the unidentifiable bird bones (mainly long bone shaft fragments) are in the ptarmigan size range and could also come from this species. The absence of substantial numbers of migratory waterfowl bones from any of the site collections is surprising. While the current archaeofauna from Selhagi on the lakeshore is too small to fully quantify, it is clearly *not* dominated by migratory waterfowl and in fact includes as many sea bird and ptarmigan bones as waterfowl, despite its location in the midst of one of the largest waterfowl nesting areas in the North Atlantic.

While a few gulls occasionally wander inland to Mývatn, the alcidae (auk family) are certainly imported by humans from the seacoast. The eider duck (*Somateria mollissimus* L.) identified from Hofstaðir rarely ascends the Laxá as far as the site and is more likely to have been taken along the coast or in the lower reaches of the river. One eider bone contained medullary bone present in females during the egg-laying season. Raven (*Corvus corax* L.) bones from Sveigakot include a nearly complete articulated leg with claws (counted as a single NISP) and need not indicate human consumption.

Bird eggshells

Smooth textured pale blue-green bird eggshells have been found on four of the five sites (excluding only Sveigakot), both as individual flecks and in

Table 3 NISP bone count for birds from the Mývatnssveit archaeofauna, with the presence of eggshell concentrations indicated xxx. (SVK = Sveigakot, HST = Hofstaðir, HRH = Hrísheimar, SBO = Steinbogi, SLH = Selhagi)

	Site	SVK 1	SVK 2	HRH 2	HST 3	SLH 1	SVK 3	HST 4	SLH 2	SBO
	Date in centuries	9th–10th	10th	10th	10th	10th	11th	Late 10th–11th	12th	Late 12th–13th
Species	Species common name									
Anatidae sp.	Duck sp.			2 + egg	egg	1 + egg	3	1 + egg	egg	
Anas platyrynchos L.	Mallard		1				3	1		1
Aythya sp.	Scaup or tufted duck		3				1	1		16
Somateria sp.	Eider duck							2		
Gavia sp.	Diver sp.			1			4			
Gavia immer L.	Great N Diver			2			1			
Gavia stellata L.	Red throated diver						1			
Podiceps auritus L.	Slavonian grebe		1				1			
Anseridae sp.	Goose sp.		2							
Cygnus sp.	Swan sp.		1	2	1	4				
Lagopus mutus L.	Ptarmigan	13	346	230 + egg	16 + egg	3 + egg	338	85	egg	9
Corvus corax L.	Raven		4							
Larus sp.	Gull sp		2							
Alca torda L.	Razorbill								1	
Uria sp.	Murre or Guillemot				6 + egg			2 + egg	1	
Fratercula arctica L.	Puffin				1					
Alle alle L.	Little auk							3		
Procellariidae sp.	Shearwater or fulmar.					egg			egg	
Aves sp.	Bird species indet.	11	274	109	52	13	177	64		33

concentrations suggesting a discarded entire eggshell. It is impossible to reasonably quantify this material (which is hard to recognise *in situ*, preserves poorly, and is nearly impossible to recover effectively in the field), but wherever possible shell was recovered and running logs of numbers of egg concentrations were maintained during excavation. In 1998 one layer of midden fill of feature G at Hofstaðir (6j) produced 37 egg concentrations within a 2 x 2 m unit, illustrating the density encountered. Identification of the recovered eggshell fragments was carried out by Jane Sidell, making use of the SEM and reference collections of the Institute of Archaeology, University College, London. The samples were sieved through a 1 mm mesh and then all eggshell was picked out. These then required additional cleaning prior to microscopy. To this end, each sample was placed in a water-filled beaker within a water filled ultrasonic tank. This process gently lifts dirt adhering to the individual pieces of shell without damaging them. The shells were then air-dried. Each sample was then scanned using a stereo microscope at magnifications of between 10 and 40 times. This was done in order to pick out superficial differences and ascribe types, based on gross morphology such as thickness and relative size of mammillae. Unusually, from these sites, some colour remained – generally colour is lost entirely as the colour of eggs is held within and organic cuticle that decays over time. In this case it would seem that some ground colour (blue/grey) is present within the crystal structure. This cannot be relied upon as an identification criterion because colour from the cuticle may have been lost, including characteristic speckling, although this has been retained in one sample, possibly through water logging. Some brown/yellow staining was also noted, and is assumed to derive from organic material present in the surrounding deposits rather than being natural shell colour. Shell thickness was measured under the microscope, with a range from 0·225–0·55 mm for the assemblage.

Sub-samples were then selected for scanning electron microscopy (SEM) using a Hitachi SEM at an accelerating voltage of 10kv and using magnification of between 25 and 1500 times. Descriptions were made of the internal surface, counts made of the mammillae/mm^2 and photomicrographs taken, generally at 300 times with several taken at 800 times.

Species identification of archaeological eggshell is generally undertaken by collecting a series of measurements and using these in conjunction with superficial external description and detailed description of the internal surface. The resulting data are then compared with modern reference material. This procedure obviously relies on reasonable preservation of the archaeological material, and relies on the inherent assumption that shell characteristics of a species have not changed through antiquity. Some of the eggshell from Iceland has proved to be too damaged to identify, however, preservation of other fragments is remarkably good.

After processing over 1000 fragments from Hrísheimar, Hofstaðir, and Selhagi, it became clear that most of the archaeologically recovered eggs derived from waterfowl, with Ptarmigan eggshell the next most common. Also present were eggshell fragments from sea birds including murre or guillemot (middle-sized alcids also represented by identified bone fragments) and a shearwater species (Table 3). Curiously, both waterfowl and marine bird eggs show evidence of hatching – suggesting some consumption of hatchling birds as well as unhatched eggs. While quantification issues are hard to resolve, it may be worth noting that the ratio of the number of waterfowl egg concentrations identified in the field logs to recovered waterfowl bones identified in these collections is on the order of 100 to 1. Eggs were extensively consumed but adult waterfowl were rarely taken.

Zooarchaeological evidence of fishery and fish consumption

Table 4 presents the fish remains identified to taxa from the Mývatn sites. Unsurprisingly, locally available freshwater salmon-family (Salmonidae) fish (arctic charr and brown trout) make up the great majority of the identified specimens. However, marine fish bones (gadidae such as cod (*Gadus morhua* L.), haddock (*Melanogrammus aeglefinus* L.), saithe (*Pollachius virens* L.) ling (*Molva molva* L.) as well as some flatfish and the wolf-fish (*Anarhichas lupus* L.) are also present. These marine fish make up 12-30% of the identifiable fish from the fully quantifiable collections, and appear in substantial numbers in the smaller Selhagi archaeofauna (despite its location directly next to one of the most productive trout fishing areas of the Laxá). Fluctuation in the relative abundance of charr and trout in the different phases probably relate to complex interactions of local and regional patterns of erosion and deforestation, alteration of streamside and lakeside ecology, changing lake nutrient cycling patterns, and climate change. A separate initial study of the recent and paleoecological

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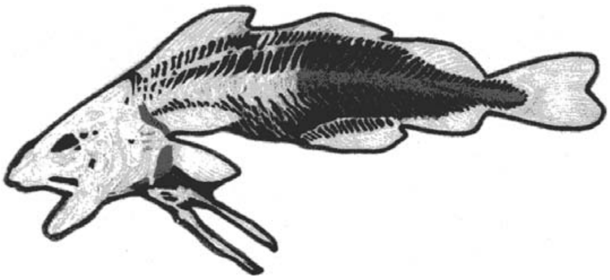
evidence for changes in freshwater fish ecology in Mývatnssveit appears in Lawson *et al*. (2005). The relative scarcity of Atlantic salmon in the archaeofauna is noteworthy, given its abundance in the lower parts of the river Laxá.

Table 5 presents the freshwater fish skeletal elements in the Mývatn archaeofauna. The salmonids are effectively represented by the whole skeleton; head, full vertebral column, and fin rays. By contrast all the salt water fish lack all mouthparts and much of the head and upper vertebrae (thoracic, precaudal, Table 6). This pattern is very consistent between phases and between sites, irrespective of sample size variability. It is not likely to be a product of differential bone survival, as the gadid mouthparts and upper vertebrae are dense bones commonly recovered from other sites in Iceland and the North Atlantic, and are substantially larger, more robust, and easier to recover than the smaller and more fragile salmonid elements or the smaller gadid caudal vertebrae. The usual method of preparing dried fish for consumption in Iceland in later time periods involved pounding with a stone hammer to tenderise the hard cured flesh, which also tends to disproportionately damage or totally destroy the smaller caudal vertebrae.

Fig. 3 presents a generalised gadid skeleton with the bone elements consistently present in the Mývatn samples indicated in darker shade. The head and upper vertebral column has apparently been filleted away and discarded at the distant fishing station supplying the processed fish. The common upper body parts found inland are the cleithra and associated bones, all traditionally left in cured fish products to help hold the beheaded body together and aid in spreading and drying the opened upper body cavity. It is clear that the preserved product imported to these inland sites from the 9th century onwards was not the later stockfish (*skreið*) cured product of the Hanseatic commercial age, as stockfish was a round-dried product containing a much higher percentage of precaudal and thoracic vertebrae (see Amundsen *et al.* in press; Krivogorskaya *et al.* 2005 for discussion). This pattern of element distribution on the five Mývatn settlement period sites (in three different environmental zones) indicates that early settlers made extensive use of freshwater fish in both lakes and streams but also felt the need to acquire cured marine fish from some coastal location.



3 Generalised gadid skeleton with the elements regularly occurring in the Mývatn archaeofauna indicated in darker tone. Most of the bones of the mouth and skull and the upper vertebrae are missing on these inland sites

Table 4 NISP count for fish bones from the Mývatnssveit archaeofauna. (SVK = Sveigakot, HST = Hofstaðir, HRH = Hrísheimar, SBO = Steinbogi, SLH = Selhagi)

	Site	SVK 1	SVK 2	HRH 2	HST 3	SLH 1	SVK 3	HST 4	SLH 2	SBO
	Date in centuries	9th–10th	10th	10th	10th	10th	11th	Late 10th–11th	12th	Late 12th–13th
Species	Species common name									
Gadus morhua L.	Atlantic cod	9	47	4	475	5	137	861	46	11
Melanogrammus aeglefinus L.	Haddock		41	17	202	4	28	248	7	10
Pollachius virens L.	Saithe		1	9	21		63	35	8	
Molva molva L.	Ling						15		1	
Brosme brosme L	Cusk							2		
Gadidae, species indet.	Gadid family	18	89	32	1071	11	211	1485	84	3
Hippoglossus sp.	Halibut				2			3		
Anarhichas lupus L.	Wolf fish				2			1		
Salvelinus alpinus L.	Arctic charr	15	227	369	693	1	341	1409	25	9
Salmo trutta L.	Brown trout	8	94	315	3413	22	111	4058	27	44
Salmo salar L.	Atlantic salmon						1	4		
Salmonidae, species indet.	Salmon family	114	967	19	2082	19	893	3329	50	41
Fish, species and family indet.	Fish species	105	641	36	1720	116	899	4113	146	33

Table 5 NISP count by bone element for freshwater salmonid fish found in the inland Mývatn archaeofauna. Most of the freshwater fish skeletons are represented in the collections. (SVK = Sveigakot, HST = Hofstaðir, HRH = Hrísheimar, SBO = Steinbogi, SLH = Selhagi)

Site	SVK 1	SVK2	HRH 2	SLH 1	HST 3	HST 4	SVK 3	SLH 2	SBO
Date in centuries	9th–10th	10th	10th	10th	10th c	Late 10th–11th	11th	12th	Late 12th–13th
Species	all salmonid	all salmonid	all salmonid	all salmonid	all salmonid	all salmonid	all salmonid	all salmonid	all salmonid
Element									
Ethmoid									
Prefrontal							1		
Vomer		2				1			
Mesethmoid		1				1			
Alisphenoid									
Parasphenoid		15	1		40	43	21	2	
Orbitosphenoid									
Supraoccipital					3	1			
Exoccipital					16	11	3		
Basioccipital					7	24	7		
Sphenotic					2	1			
Pterotic		1	1		6	11	4		
Epiotic		6		1		20	8		
Opisthotic									
Prootic					10	5			
Otolith									
Nasal									
Frontal		2			9	4	2		
Parietal									
Supratemporal									
Premaxilla		2	1			4	2		
Maxilla		9			10	21	6		
Supraorbital									
Lachrymal									
Suborbital					3	6			
Dentary		27	13	1	66	68	26	2	
Angular		40	1	1	74	97	63		1
Retroarticular									
Suprapreopercle									
Preopercle		3			24	7	3		
Supramaxilla									
Opercle		4			24	9	17		
Subopercle					2				
Interopercle		2			4	24			
Branchiostegal Ray		1				17	4		
Palatine		3			6	6	6		
Ectopterygoid									
Quadrate		19	1		14	62	31	1	1
Mesopterygoid		1			19	11			
Metapterygoid		1			17	16	7		
Hyomandibular		30	5	5	97		44	1	2
Symplectic		1							
Interhyal									
Epihyal		12			15	30	9		2
Ceratohyal	1	37	31	1	66	93	53	1	10
Hypohyal					1				
Basihyal									
Pharyngeal Plate					5	8			
Epibranchial		1			1	6		1	
Ceratobranchial		2			7	76	4		
Hyporanchial		2			1		4	1	
Basibranchial									
Basibranchial plate									
Urohyal		2			29		5		
Pharyngobranchial					1	1	1		
Posttemporal					4	1	4		
Supracleithrum					5	3	4		
Scapula		2			5	13	2		

Table 5 ***Continued***

Site	SVK 1	SVK2	HRH 2	SLH 1	HST 3	HST 4	SVK 3	SLH 2	SBO
Date in centuries	**9th–10th**	**10th**	**10th**	**10th**	**10th c**	**Late 10th–11th**	**11th**	**12th**	**Late 12th–13th**
Species	**all salmonid**	**all salmonid**	**all salmonid**	**all salmonid**	**all salmonid**	**all salmonid**	**all salmonid**	**all salmonid**	**all salmonid**
Cleithrum				1	3	14			
Postcleithrum						44			
Coracoid		11	1	1	23	49	10	1	
Mesocoracoid						2	1		
Radials									
Basipterygium	1	19			45	73	11		
Interrhaemal spine			1		9		2		
Vertebral frags	8	9	20	1	62	675	51		13
Atlas	1	9	5		10	38			
Thoracic		239	150		1044	1540	33	2	8
Precaudal	13	158	116	10	909	969	301	8	10
Caudal	40	533	520	17	3432	4644	559	77	46
Penultimate						3	4		
Ultimate					1	2	2		1
Hypural		2			11	37	1	1	
Uroneural						50			
Epural									
Caudal bony plate					7				
Expanded neural spine									
Expanded haemal spine									

Table 6 NISP count by bone element for marine gadid fish found in the inland archaeofauna from the Mývatn region. Partial skeletons are present, mainly bones around the gill slit (cleithrum and clavicula) and lower vertebrae (SVK = Sveigakot, HST = Hofstaðir, HRH = Hrísheimar, SBO = Steinbogi, SLH = Selhagi)

Site	SVK 1	SVK2	HRH 2	SLH 1	HST 3	HST 4	SVK 3	SLH 2	SBO
Date in centuries	**9th–10th**	**10th**	**10th**	**10th**	**10th**	**Late 10th–11th**	**11th**	**12th**	**13th**
Species	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**
Element									
Ethmoid									
Prefrontal					1				
Vomer									
Mesethmoid						1			
Alisphenoid									
Parasphenoid					6	3			
Orbitosphenoid									
Supraoccipital					10	13			
Exoccipital									
Basioccipital					2	10			
Sphenotic									
Pterotic						4			
Epiotic						3			
Opisthotic									
Prootic						1			
Otolith									
Nasal					1				
Frontal									
Parietal									
Supratemporal									
Premaxilla									
Maxilla					3	7			
Supraorbital									
Lachrymal									
Suborbital									
Dentary									
Angular					1		1		

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As indicated by Table 7 some fragments of marine shellfish have also been recovered from the Mývatn sites, including very worn and battered clam shells (*Mya* sp.) which could have served as spoons or another artefactual use (clam shells have also been recovered from the 10th-century inland site of Granastaðir in Eyjafjord district, Einarsson 1994). Especially at Hofstaðir and Hrísheimar, numbers of tiny (2 cm long and smaller) mussel shells (*Mytilus edulis* L.) were found in concentrations in the midden layers, often partially burnt and in ash-rich contexts. These are unlikely to be part of direct human diet (some were recovered still closed) but the concentrations resemble those found in the root ball of sea

Table 6 ***Continued***

Site	SVK 1	SVK2	HRH 2	SLH 1	HST 3	HST 4	SVK 3	SLH 2	SBO
Date in centuries	**9th–10th**	**10th**	**10th**	**10th**	**10th**	**Late 10th–11th**	**11th**	**12th**	**13th**
Species	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**	**all gadid**
Retroarticular									
Suprapreopercle									
Preopercle					1	1			
Supramaxilla									
Opercle						2			
Subopercle									
Interopercle									
Branchiostegal ray		1			4	21	3		
Palatine									
Ectopterygoid					1				
Quadrate							1		
Mesopterygoid						8			
Metapterygoid									
Hyomandibular					4				
Symplectic									
Interhyal									
Epihyal									
Ceratohyal		1			4				
Hypohyal									
Basihyal									
Pharyngeal plate									
Epibranchial									
Ceratobranchial					2				
Hyporanchial					1	1			
Basibranchial									
Basibranchial plate									
Urohyal					2				
Pharyngobranchial									
Posttemporal					1	3			
Supracleithrum		1		2	3	20		1	
Scapula	3	20	4	1	79	154	44	7	1
Cleithrum		18	21	5	831	1117	114	65	15
Postcleithrum	1	16	2		224	391	30	4	
Coracoid					29	40			
Mesocoracoid									
Radials									
Basipterygium		2			16	24	1		
Interrhaemal spine								12	
Vertebral frags	12	17		2	43	45	7	2	1
Atlas		1							
Thoracic		5	1		2	9	10		
Precaudal		3			2		50		
Caudal	11	77	34	5	470	824	193	46	7
Penultimate									
Ultimate									
Hypural					4	11			
Uroneural									
Epural									
Caudal Bony plate									
Expanded neural spine									
Expanded haemal spine									

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weed (*Laminaria* sp.) collected after storms in several locations along the shores of Skjálfandi Bay to the north. These may well be associated with sea weed collection for fodder, bedding or for salt extraction (involving burning) documented at other Norse sites throughout the North Atlantic (Buckland 2000). The concentration of these tiny mussels at Hofstaðir and their association with ash layers may reflect particularly intense salt production efforts at this site.

Modern wildlife and historic patterns of human use

The Mývatn lake basin has been a centre for natural science research since the 19th century. Table 8 presents modern data on seasonality, density, and location of the wild species identified in the 9th–13th-century archaeofauna. Ducks are perhaps the most characteristic part of the modern Mývatn wildlife. The first migrants appear in April when ice-free areas begin to expand. In early-mid-May most of the migrants have arrived and the lake ice has gone. About 15,000 duck pairs of 15 species arrive in the area and join about 1000 ducks that have over-wintered (mostly Barrow's goldeneye *Bucephala islandica* L. and mallard *Anas platyrhynchos* L.) (Gardarsson 1979; 1991). The most abundant species are tufted duck (*Aythya fuligula* L.) that immigrated just before 1900, greater scaup (*Aythya marila* L.) and Eurasian wigeon (*Anas penelope* L.). In mid-summer some of the male ducks leave for their moulting grounds at sea, but most stay behind for moulting their flight feathers and have their numbers augmented by males coming from neighbouring districts (Einarsson and Gardarsson 2004). The migrant birds leave in September-October and the lake normally freezes over in October.

Harvesting duck eggs has been a traditional way of exploiting the waterfowl populations at Mývatn (Gudmundsson 1979). Duck egg harvesting was first mentioned in the 1712 *Jarðabók* land register, taking place at 11 farms bordering the lake (JÁM 1990). Interestingly, in the Jarðabók register the Kráká valley sites closest to the egg-rich abandoned Hrísheimar site (Baldursheimar and Gautlönd) were not recorded as having egg collection access- perhaps reflecting environmental or social changes since the 10th century (Table 9). The annual harvest of about 4000 eggs in the Jarðabók register is probably understated because of fear for taxation. A number ten times higher (about 41,000) was obtained in Gudmundssons (1979) inquiry in 1941. 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). Although duck hunting seems to have been the exception during the last 180 years or so (Gudmundsson 1979), numerous diving water birds get drowned in gill nets used for char and trout fishing (Gardarsson 1961).

Apart from ducks, a few other species need to be mentioned. Horned (Slavonian) grebes (*Podiceps auritus* L.) are common but nest and moult mainly in the northern part of the Mývatn area (Einarsson 2000). The total number of nests is between 250 and 325. There is a large colony at Sandvatn (ytra), within reach from Hofstaðir (4 km). A few pairs nest in the neighbourhood of Selhagi and Hrísheimar but Sveigakot is quite far away (5 km or more) from any present grebe habitat. Only few pairs of each of the diver species (great northern diver *Gavia immer* L. and red-throated diver *G. stellata* L.) breed in the Mývatn area. Whooper swans (*Cygnus cygnus* L.) nest sparsely in the Mývatn area, but flocks of moulting swans occur on Lake Mývatn and Lake Sandvatn (sydra) in mid-summer (Gardarsson and Einarsson 2002). Open water in the winter sustains 150–260 swans (Gardarsson and Skarphédinsson 1985), some of these ice-free areas are at

Table 7 NISP count for molluscan shell fragments. (SVK = Sveigakot, HST = Hofstaðir, HRH = Hrísheimar, SBO = Steinbogi, SLH = Selhagi). Note that the large numbers of mussel shells from Hofstaðir (HST) come from tiny individuals (*c.* 5–20 mm long) probably brought to the site in seaweed root balls

Site	SVK 1	SVK 2	HRH 2	HST 3	SLH 1	SVK 3	HST 4	SLH 2	SBO
Date in centuries	9th–10th	10th	10th	10th	10th	11th	Late 10th–11th	12th	Late 12th–13th
Species									
Common mussel *Mytilus edulis* L.		6	13	116			22		
Clam species indet.		2	10	21	3	1	7	1	2
Shellfish species indet.	1	5		81			376	1	6

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Grænavatn, close to Sveigakot, at Laxá close to Selhagi and also by Hofstaðir. Two species of geese nest in the region. The greylag goose (*Anser anser* L.) is common around Lake Mývatn and the pink-footed goose (*Anser brachyrhynchus* Baillon) being a highland species nests at the southern border of the Mývatn area. Both species are increasing in numbers and the pink-footed goose is expanding its range northwards, within the study area. The upland heaths of north-eastern Iceland (including the Mývatn area) are the present-day key habitat for the Icelandic population of ptarmigan. It occurs at spring densities ranging from 1·8 to 11·8 males per km^2 at Hofstaðir but higher densities in the lower-lying region towards the sea (Nielsen 1995). The nearest seabird cliffs are found in the island of Grímsey, some 100 km from Mývatn and about 60 km from the mouth of the river Laxá; and Raudinúpur at the tip of the Melrakkaslétta peninsula, 100 km from Mývatn. These cliffs have mixed colonies of thick-billed and common murres (guillemots) (*Uria lomvia* L. and *U. aalge* L.) and razorbills (*Alca torda* L.). The Mánáreyjar islands, 8 km off the tip of the Tjörnes peninsula and 70 km from Mývatn have a small

Table 8 Modern distribution and population estimates for wild species appearing in the 9th–13th centuries archaeofauna, with authorities

Species	Season	Distance	Density/colony size	References
BIRDS				
Gavia immer	summer	local	0·5 birds/100 ha water	Gardarsson and Einarsson 2002
Gavia stellata	summer	local	0·4 birds/100 ha water	Gardarsson and Einarsson 2002
Podiceps auritus	summer	local	250–325 nests	Einarsson 2000
			4·5 birds/100 ha water	Gardarsson and Einarsson 2002
Cygnus cygnus	winter	local	Winter: 1·3 birds/100 ha water	Gardarsson and Einarsson 2002
	summer	local	Spring: 3·6 birds/100 ha water	Gardarsson and Einarsson 2002
		local	Moult: 13·1/100 ha water	Gardarsson and Einarsson 2002
Anser anser	summer	local	hundreds	
Anser brachyrhynchus	summer	highland (10 km)	hundreds	
Anas platyrhynchos	summer	local	5·7 birds/100 ha water	Gardarsson and Einarsson 2002
	winter	local	1·2 birds/100 ha water	Gardarsson and Einarsson 2002
Aythya spp.	summer	local	Spring: 262·2 birds/100 ha water	Gardarsson and Einarsson 2002
		local	Moult: 126·5 males/100 ha water	Gardarsson and Einarsson 2002
Somateria mollissima	summer	coastal (40 km)	Spring: up to 4600 nests at Laxamýri and Flatey	Gunnarsson and Pálsson 1988
	winter		Up to 8800 birds	Gunnarsson and Pálsson 1988
Lagopus mutus	all year	local	Spring: 5·7 males/km^2	Nielsen 1995
Uria spp.	summer	Grímsey (100km)	Colony: 70,000 pairs	Gardarsson 1995
		Raudinúpur (100km)	Colony: 2900 pairs	Gardarsson 1995
	winter	Skjálfandi bay	Thousands	Gunnarsson and Pálsson 1988
Alle alle	winter	Skjálfandi bay	Common	Gunnarsson and Pálsson 1988
Alca torda	summer	Grímsey (100km)	Colony: 32,000 pairs	Gardarsson 1995
		Mánáreyjar (70 km)	Colony: 60 pairs	Gardarsson 1995
		Raudinúpur (100km)	Colony: 840 pairs	Gardarsson 1995
	winter	Skjálfandi bay	Very common	Gunnarsson and Pálsson 1988
Laridae	all year	local or coastal depending on species	Abundant	
Corvus corax	all year	local	Common	
FISH				
Salmo salar	summer	Laxá Lower reaches 24–42 km from Hofstadir	c. 900 salmon per year in traps in 1899–1929	Hafstein 1965
Salmo trutta	all year	Laxá, Myvatn	68–115 fish/ha	Gíslason et al. 2002
		Other lakes	24–48,000 fish (exploitable stock in Laxá)	
			Catch 1970–2000 1875 fish/year in Myvatn	Gudbergsson 2004
Salvelinus alpinus	all year	Myvatn	Catch 1930–69 29,400 fish/year	Gudbergsson 2004
		Other lakes		
Gadus morhua	all year	Skjálfandi bay	Abundant	Th. Thorarinsson pers. comm.
Melanogrammus aeglefinus	all year	Skjálfandi bay	Abundant	Th. Thorarinsson pers. comm.
MAMMALS				
Alopex lagopus	all year	local	Not uncommon	I. Yngvason pers. comm.
Phocoena	all year	Skjálfandi bay	Common	Th. Thorarinsson pers. comm.
Seal sp.	all year	Skjálfandi bay	Common	Th. Thorarinsson pers. comm.

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colony of razorbills (Gardarsson 1995). Puffins (*Fratercula arctica* L.) nest in large numbers in the islands of Grímsey, Mánáreyjar and Lundey (Skjálfandi bay) and in smaller numbers on the Tjörnes peninsula. In winter, both *Uria* species and the razorbill are common on the Skjálfandi bay, that part of the Arctic Ocean closest (50 km) to Mývatn, and the little auk (*Alle alle* L.) is not uncommon. The numbers of little auk seem to be temperature related, only few birds are observed in mild winters whereas in cold winters they occur by the thousand (Gunnarsson and Pálsson 1998). A sizeable eider colony is at the mouth of the river Laxá, but a small number of eiders nest along the river some 20 km upstream. Table 8 summarises the present day distribution of wild species appearing in the Viking Age archaeofauna and provides population estimates where available.

Freshwater Ecology

The location of Lake Mývatn at the edge of the volcanic zone has profound effect on its ecology. The underground channels feeding the lake drain a large watershed which is covered with postglacial and porous lava fields and volcanic edifices. When the water reaches Lake Mývatn it is rich in minerals, especially phosphate which fertilises the lake. Together with tepid silica-rich water originating in local geothermal fields these waters create a naturally eutrophic water system that is in sharp contrast with the rather nutrient-poor lakes and ponds in the surrounding wetlands (Jónasson 1979; Einarsson *et al.* 2004; Einarsson and Gulati 2004; Einarsson *et al.* 1988). The rich growth of diatoms in the lake is channelled through the food web to a myriad of chironomid (non-biting) midge larvae that emerge as adult flies in spring and mid-summer to form massive mating swarms on the lake shores, giving Mývatn its name (*Mývatn* = midge lake). The midge larvae together with the adult midges are the main food source for the wildlife in the area other than ptarmigan.

Table 9 Listing of resources available to farms in the early 18th century, from the 1712 Jarðabók land survey (JAM 1990). Statistical data from Edvardsson (2004a)

Jarðabók Land Register Autumn AD 1712 (data from Edvardsson 2003)

	x = resource available				
Farm	**Birch**	**Trout**	**Eggs**	**Location**	**Site near**
Sveinströnd	x			*Kráká*	
Baldursheimur	x			*Kráká*	Hrísheimar
Gautlönd	x			*Kráká*	Hrísheimar
Grænavatn	x		x	*Kráká / Lake*	Sveigakot
Grímstaðir	x	x	x	*Lakeside*	
Kálfaströnd		x	x	*Lakeside*	
Geiteyjarströnd		x	x	*Lakeside*	
Vogar		x	x	*Lakeside*	
Reykjahlíð		x	x	*Lakeside*	
Ytri Neslönd		x	x	*Lakeside*	
Haganes		x	x	*Lakeside*	Selhagi
Garður		x	x	*Lakeside*	
Geirastaðir	x	x	x	*Lakeside*	
Skútustaðir	x	x	x	*Lakeside*	
Briamsnes		x		*Lakeside*	
Fagranes	x	x		*Lakeside*	
Vindbelgur		x		*Lakeside*	
Arnarvatn	x	x	x	Laxá	Steinbogi
Hofstaðir	x	x		Laxá	Hofstaðir

The situation is different in the effluent river Laxá where phytoplankton drifting from the lake makes a rich food-source for filter-feeding blackfly (*Simulium*) larvae. The larvae living near the outlet have access to the richest supply but as they are very effective in filtering the river water there is less food left for those living further downstream. This competition among the larvae creates a downstream gradient in production (Gíslason 1994). Downstream larvae are fewer and more slow-growing. This gradient is reflected in the wildlife that feeds on the blackfly larvae, the ducks (mostly harlequin duck *Histrionicus histrionicus* L. and Barrow's goldeneye) and brown trout which concentrate at the river outlet (Einarsson *et al.* in press). The outlet area is the richest part of the river, in fact the richest freshwater site in Iceland (e.g. Gislason 1994). The Selhagi site would be ideally situated in this respect, having access to the richest part of the river but also to the lake. The location of Hofstaðir would be less ideal from this perspective, but to make up for that an almost 90 degrees turn in the river channel provides the farm with access to an extra stretch of the river. Atlantic salmon migrates up the river Laxá in large numbers from the sea in spring but is not able to pass waterfalls midway between the sea and Lake Mývatn. Above the waterfalls the brown trout is the dominant fish species.

The fishing tradition in the Mývatn area, first listed in the 1712 land register, was by gill netting and beach seining in the river and lake in summer and in winter by gill netting and by hook and line from the ice (JAM 1990). Some netting from the shore also took place in ice-free areas in winter. Gill netting of trout or charr is mentioned in Lakes Arnarvatn and Sandvatn sydra. Little fishing took place in Lake Grænavatn or the Kráká by the 18th century, though trout bones are recovered in quantity from Sveigakot near Graenavatn and from Hrísheimar between

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Baldursheimur and Gautlond, again suggesting changes in ecology or resource use-rights since the 10th century (Table 9).

Discussion

The combined evidence of well dated archaeofauna from multiple contemporary sites, the written records of historical resource use, and the modern environmental data may allow a number of observations:

Convergence between the archaeological evidence and modern and historic patterns of species distribution is notable, but some exceptions may flag areas of environmental change since the 9th–11th centuries. The discontinuities that appear in the evidence for distribution of birds, egg collection rights, and trout fishing between the Viking Age archaeological data, 18th-century Jarðabók and the 19th-century to modern observational record cluster in the zone south of Mývatn in the area of the Kráká valley. The Kráká appears to have undergone alteration from a wood-/herb-bordered stream draining a southern highland catchment largely stabilised under a shrub/grass groundcover into a wandering braided stream seasonally carrying a huge burden of silt from a largely denuded catchment zone sometime in the later Middle Ages–Early Modern period. When the Kráká area archaeofauna were deposited in the 9th to 11th centuries, substantially different patterns of vegetation and drainage certainly existed. The upper Laxá valley and the lakeside region appear to have been less affected by large-scale environmental change. Soil science investigations have also stressed different trajectories in the Kráká drainage vs. the Laxá (Simpson *et al.* 2004). Where comparable coverage is available, environmental archaeology can combine effectively with modern ecology and geomorphic modeling to contribute to a more effective reconstruction of changes in landscape and resource distribution.

The pattern of sustainable waterfowl egg harvesting by the local community of Mývatnssveit known from historical sources to extend to the early 19th century can now be shown to extend a further thousand years into the past. While long term sustainable resource use is an expressed goal of most current national and international environmental programs, and sustainability has been claimed for many ethnographically known traditional landuse practices, it is rare to find such multi-stranded evidence for actual sustainability on the millennium scale. Despite erosion of pastures, climatic cooling, and sometimes desperate poverty, the people of Mývatnssveit have successfully managed their lake and its migratory waterfowl for 1100 years.

The inland distribution pattern of coastal species (sea bird bone and eggs, sea mammals, and sea weed as well as marine fish) raises intriguing questions about the scale and degree of integration of Viking Age chiefly economies in the North Atlantic. The range of marine resources present on the inland Mývatnssveit sites suggests the presence of social and economic networks that tied together substantial areas of early Iceland. A similar pattern of partial marine fish skeletons at the mid- 10th-century site of Granastaðir (50 km inland from Eyjafjord in N Iceland; Einarsson 1994), cod vertebrae from Aðalból (95 km from the sea in the eastern valley of Hrafnkelsdalur; Amorosi 1996), and finds of marine mammal bones at the inland farms Reykholt and Háls in SW Iceland (65–70 km from the sea) indicate that the Mývatn pattern of coastal connection to inland sites is not unique in Iceland. In Greenland, the presence of substantial amounts of seal bone, marine bird bone and small amounts of marine fish bone likewise suggest systematic integration of coastal resources with inland farm economies (Enghoff 2003; McGovern 1985). It seems clear that we must look beyond not only the individual farm as the ultimate unit of subsistence and survival but also beyond the immediate 'catchment zone' of the multi-farm district (Icel. *Hreppur*) to more fully understand the economic and social dynamics of Viking Age North Atlantic settlement.

The 'consumer's pattern' of cured fish in these 9th–11th-century inland Icelandic sites provides a contrast to the more usual mixed pattern of superposed processing and consumption debris common on North Atlantic coastal sites. The consistency of patterning in the inland gadid remains indicates both the widespread demand and the widespread availability of cured fish products during the early Viking period in what was then a frontier area of Nordic expansion. The 9th–11th-century patterns of fish butchery and high species diversity seem distinct from the patterns of the later Medieval to early Modern cod-dominated stockfish trade (Amundsen *et al.* 2005; Perdikaris 1999; Perdikaris and McGovern in press; Edvardsson 2005b; Edvardsson and McGovern 2005; Krivogorskaya *et al.* 2005). Barrett *et al.* (2004a; 2004b) have demonstrated a marked 'fish event horizon' in multiple archaeofauna from Britain, demonstrating that prior to *c.* AD 950–1050 marine fish bones are exceedingly rare on any inland British site. After the mid-11th century,

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marine fish (especially herring and cod) become common on inland British sites, and the historically documented impact of the growing international fish trade becomes clear in the archaeological record. The Mývatnssveit archaeofauna both pre-date and post-date the British fish event horizon with little apparent change across the horizon period. In rural Iceland, steady consumption of processed marine fish began with initial settlement in the last quarter of the 9th century and continued down to the present. It appears that regional level production and exchange of preserved marine fish (showing considerable variety of species and curing technique employed) was indeed a feature of the 9th–10th-century Nordic economy in some parts of Scandinavia prior to the historically known rise of commercial fisheries by 1100. This early pre-commercial, regional-scale tradition of cured marine fish production and distribution thus provided the later Viking age Scandinavians with a potential for economic intensification which may have produced the specialised 'fish middens' and the clear fish event horizon around the year 1000 in the British Isles. It may not be an accident that the British fish event horizon of AD 950–1050 coincides with a peak in Anglo-Scandinavian interaction and the brief union of English and Scandinavian ruling houses under Knut 'the Great' (died AD 1039). In any case, the Icelandic evidence suggests that Scandinavian elites had a good grasp of the potential of cured fish as a staple product well before AD 950.

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